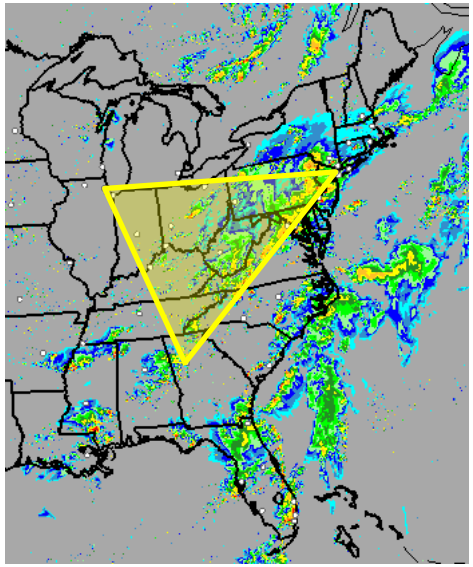
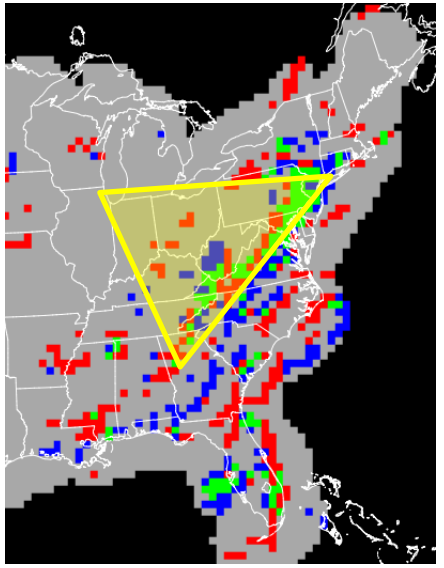
HRRR Changes Retro-Run Assessment Results

21 June 2012



NOAA/ESRL/GSD/AMB

Curtis Alexander,
Steve Weygandt, Stan Benjamin,
David Dowell, Tanya Smirnova,
Ming Hu, John Brown,
Patrick Hofmann, Eric James,
and Haidao Lin



Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

Replaced RUC at NCEP 05/01/12

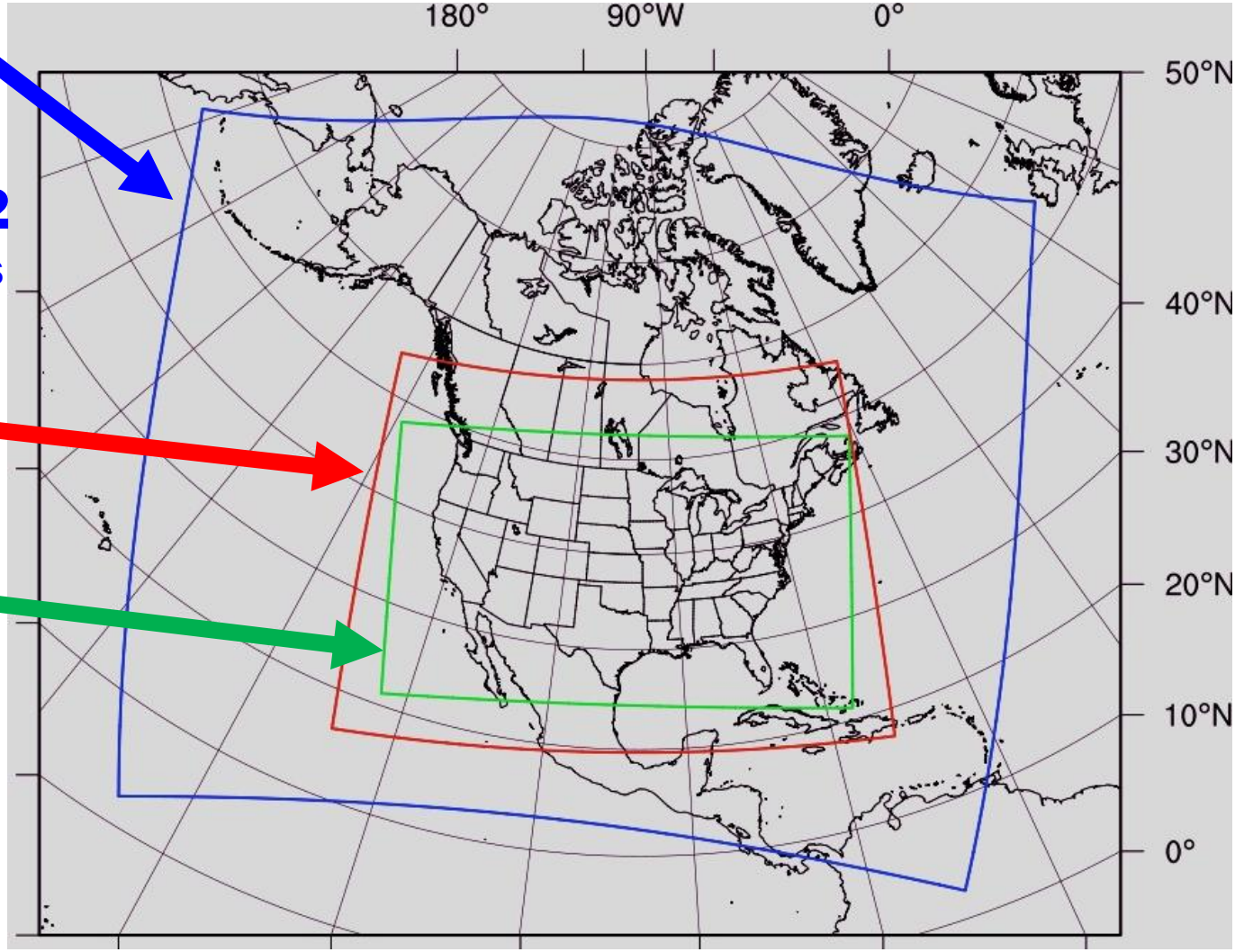
WRF, GSI, RUC features

13km RUC (mesoscale)

3km HRRR (storm-scale)

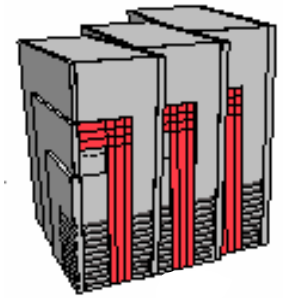
High-Resolution Rapid Refresh

Experimental 3km nest inside RAP, hourly 15-h fcst

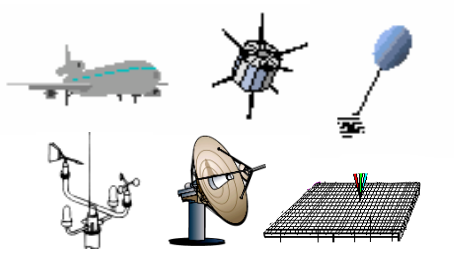


RAP: Data assimilation engine for HRRR

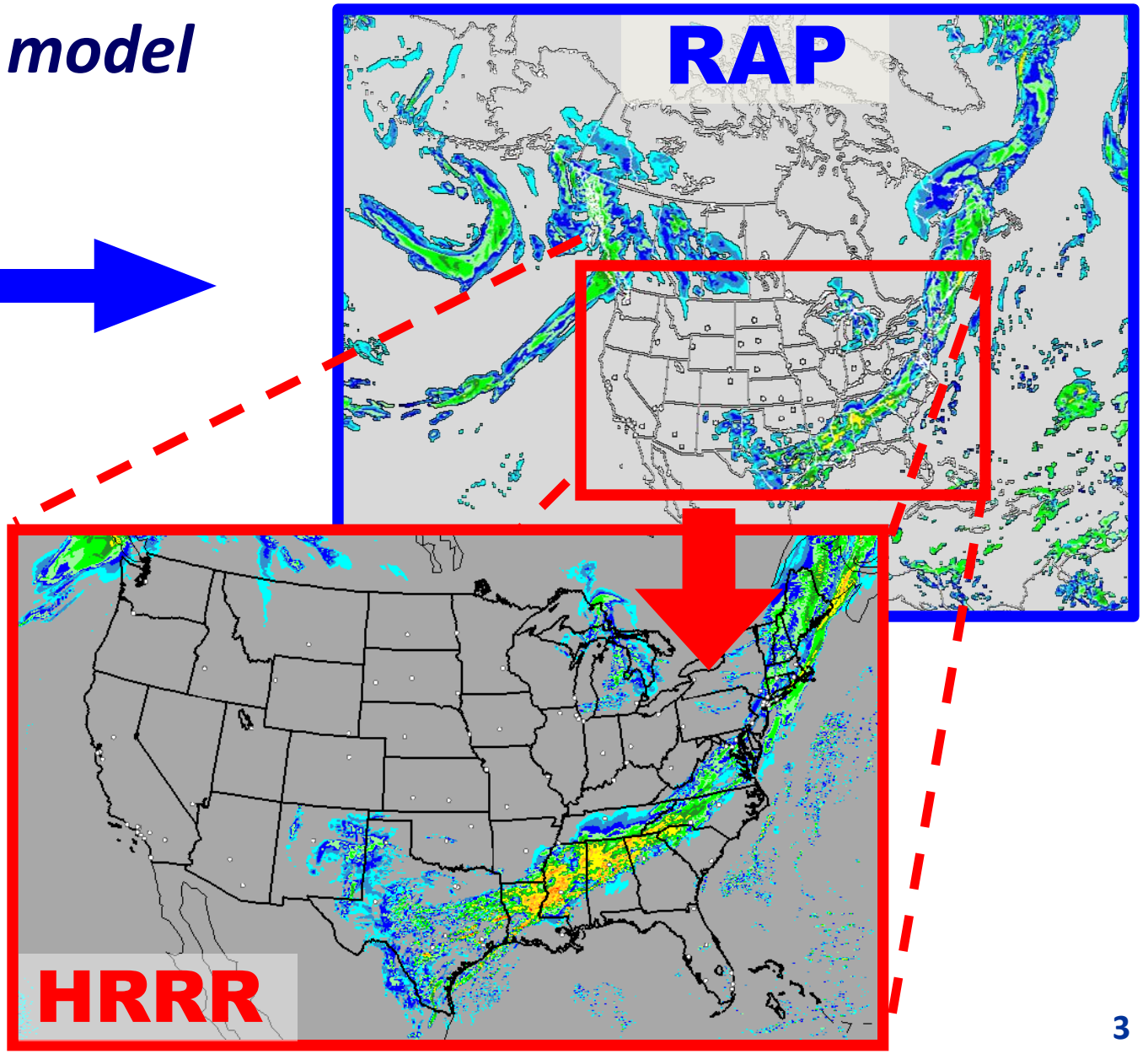
Hourly cycling model



Data Assimilation cycle



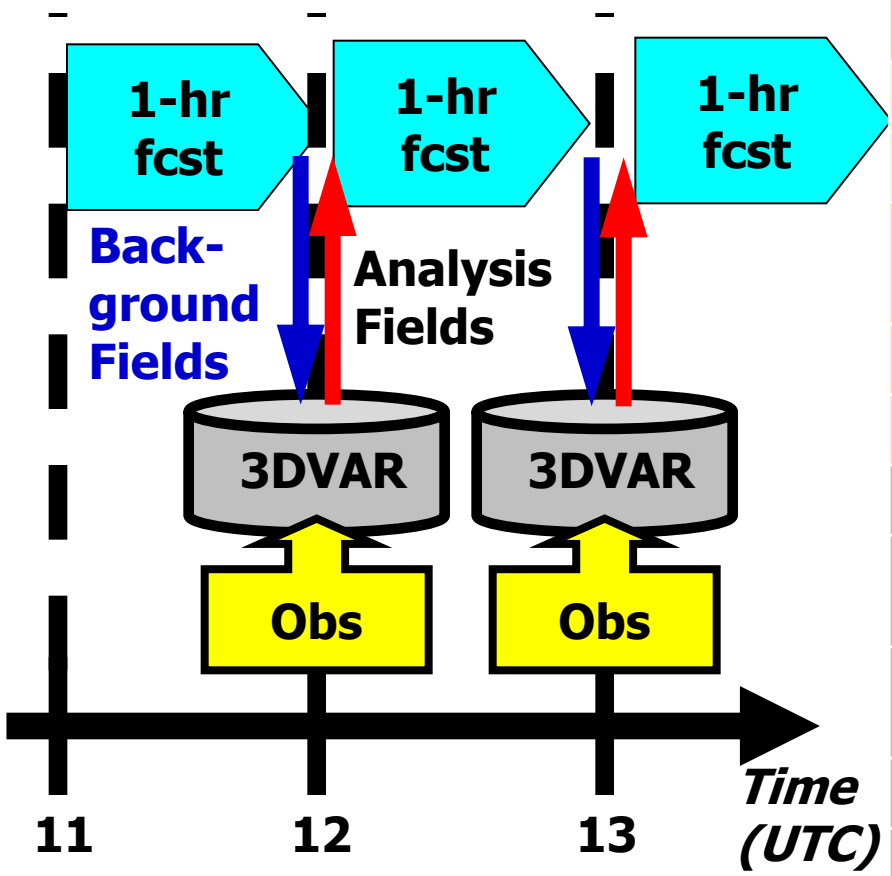
Observations



Rapid Refresh
Hourly Update Cycle

Partial cycle atmospheric fields – introduce GFS information 2x/day

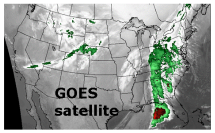
Fully cycle all land-sfc fields

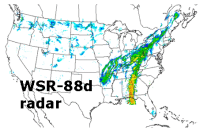


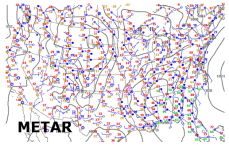
Hourly Observations	RAP 2012 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	2km
Lightning (proxy reflectivity)	NLDN, GLD360
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
Mesonet (T, Td, V, ps)	flagged
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top pressure/temp	13km
GPS – Precipitable water	
WindSat scatterometer	2-10K

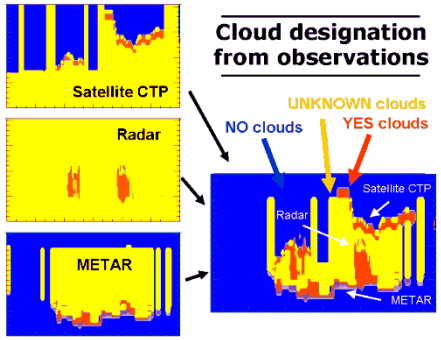
Rapid Refresh Specific Analysis Features

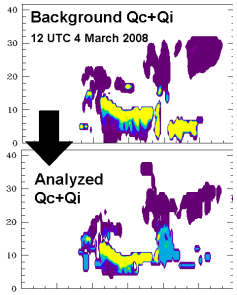
Cloud and hydrometeor analysis



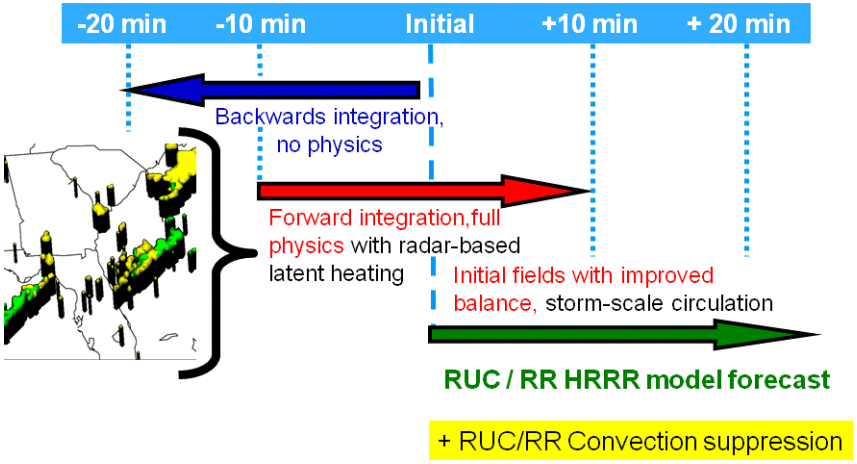








Digital filter-based reflectivity assimilation (DDFI)



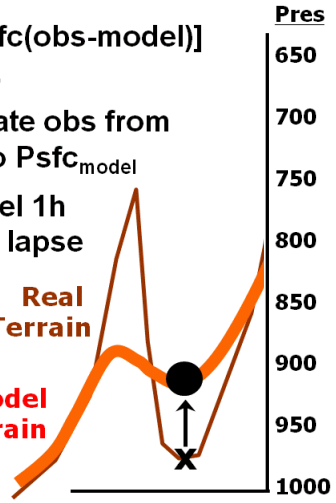
Special treatments for surface observations

Elevation correction

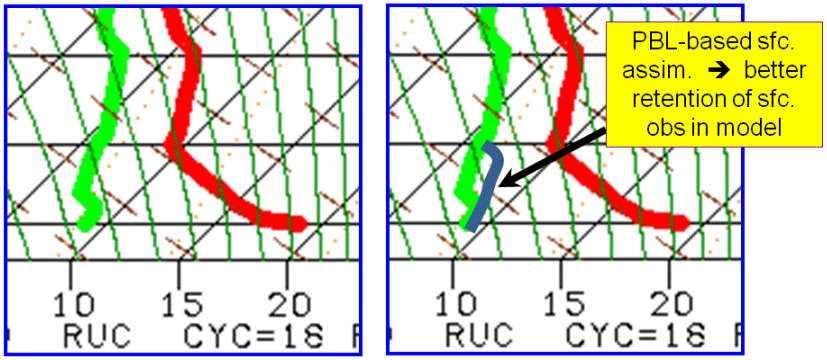
If abs[Psfc(obs-model)] < 70 hPa.

Extrapolate obs from $Psfc_{obs}$ to $Psfc_{model}$

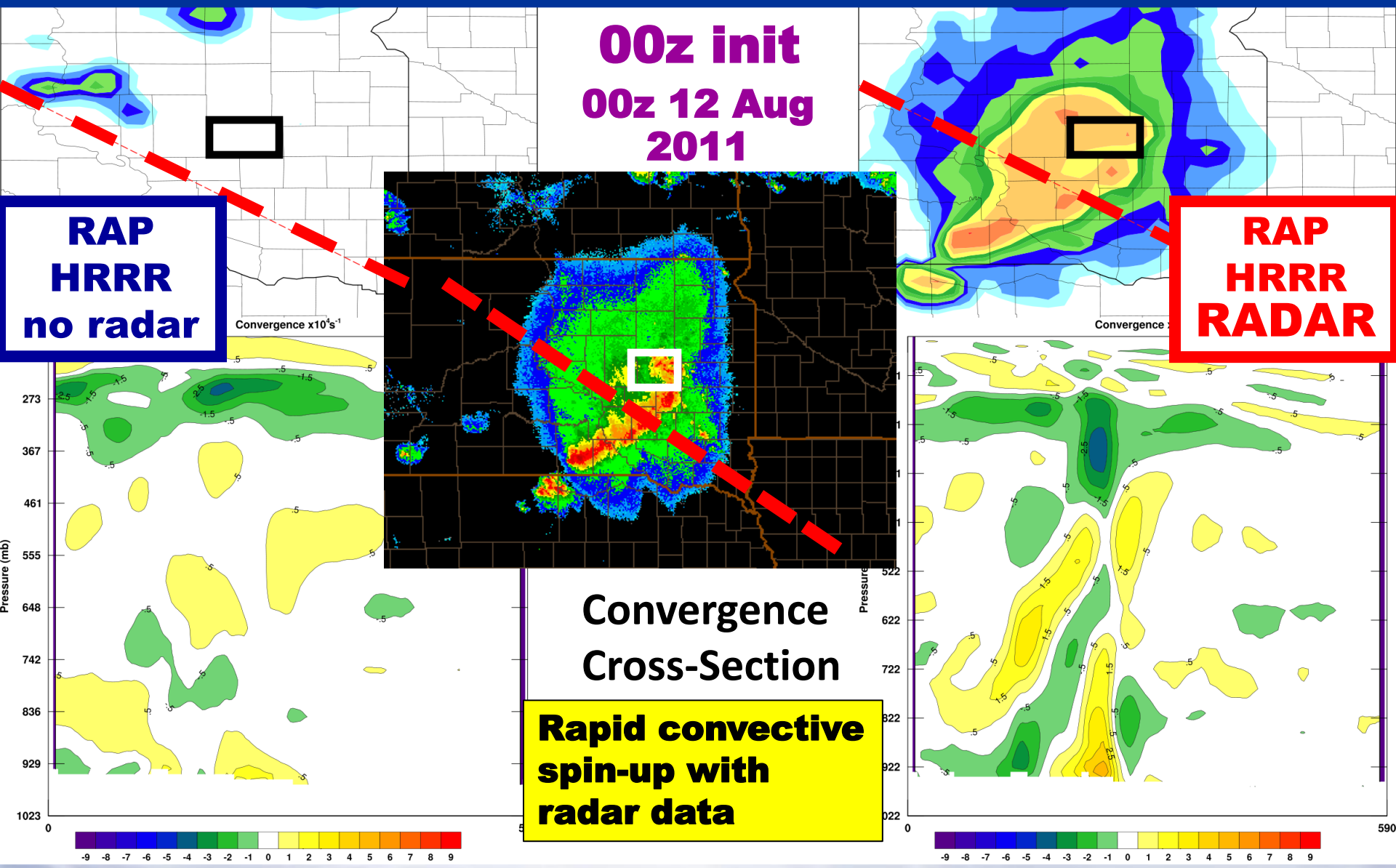
Use model 1h low-level lapse rate.



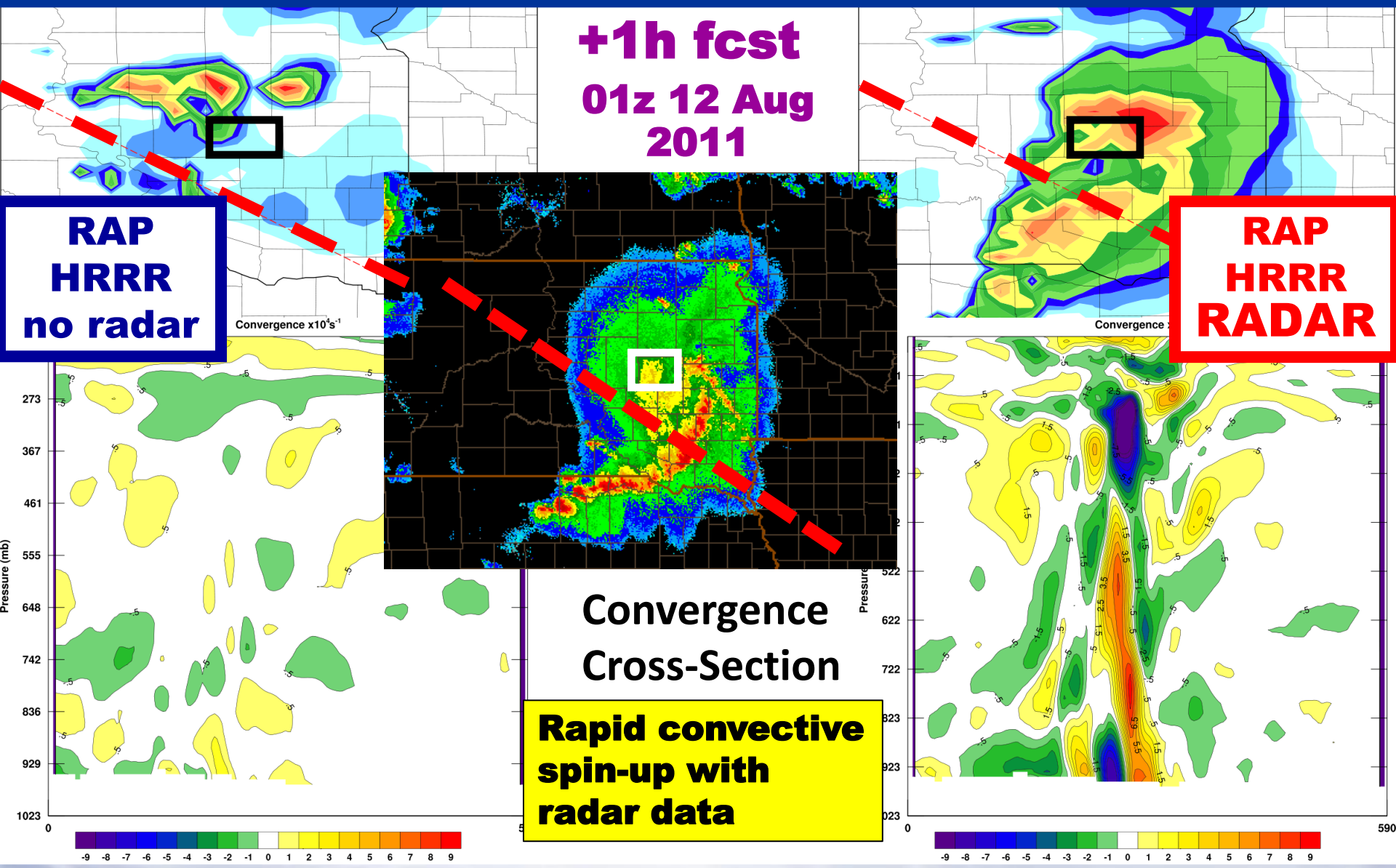
PBL-based pseudo-observations



Radar Reflectivity Assimilation

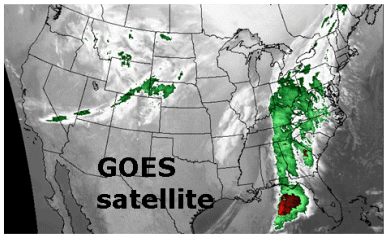


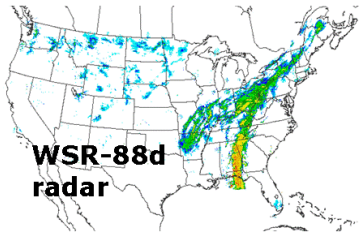
Radar Reflectivity Assimilation

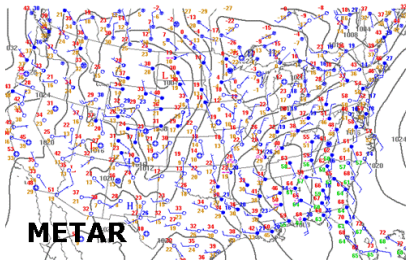


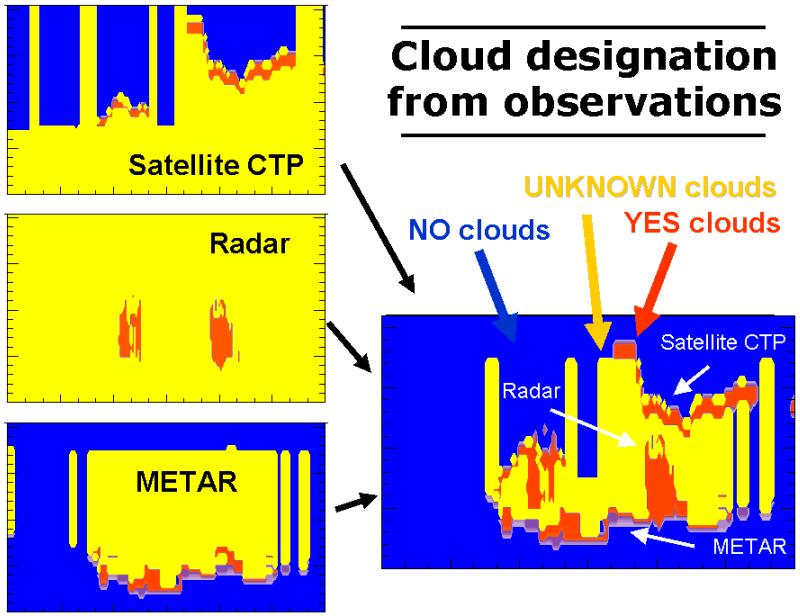
RAP Specific Analysis Features

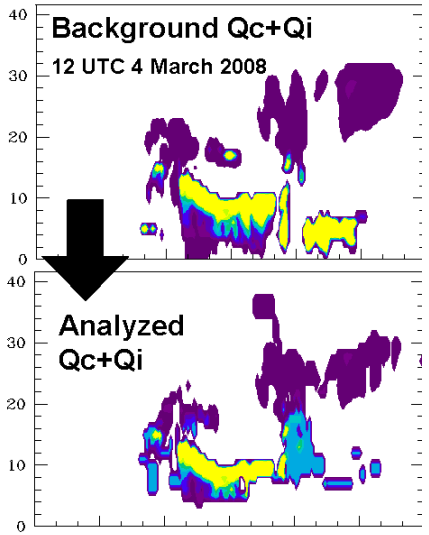
Cloud and hydrometeor analysis









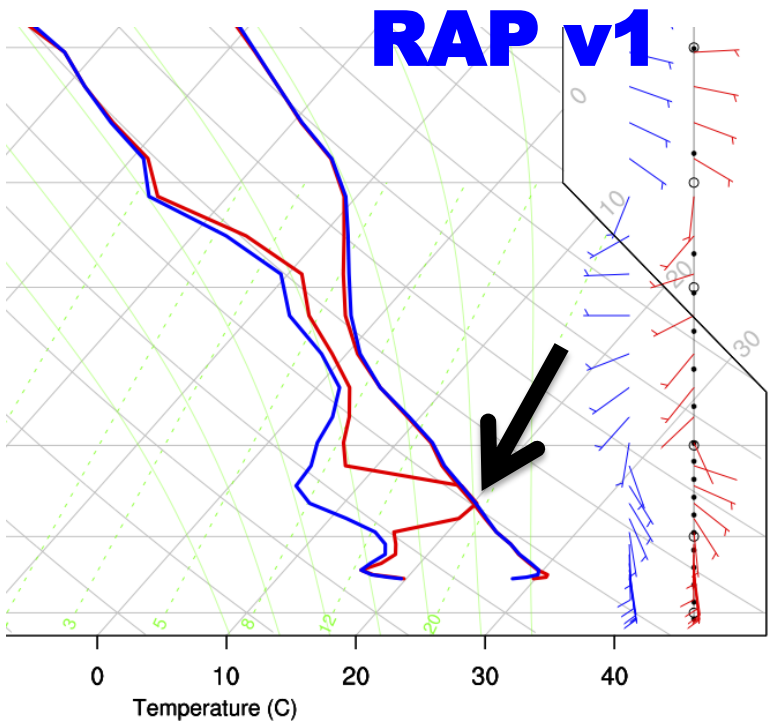


RAP v2 improvements:

(1) Conserve virtual potential temperature for cloud building

(2) Building of low-level clouds from GOES data

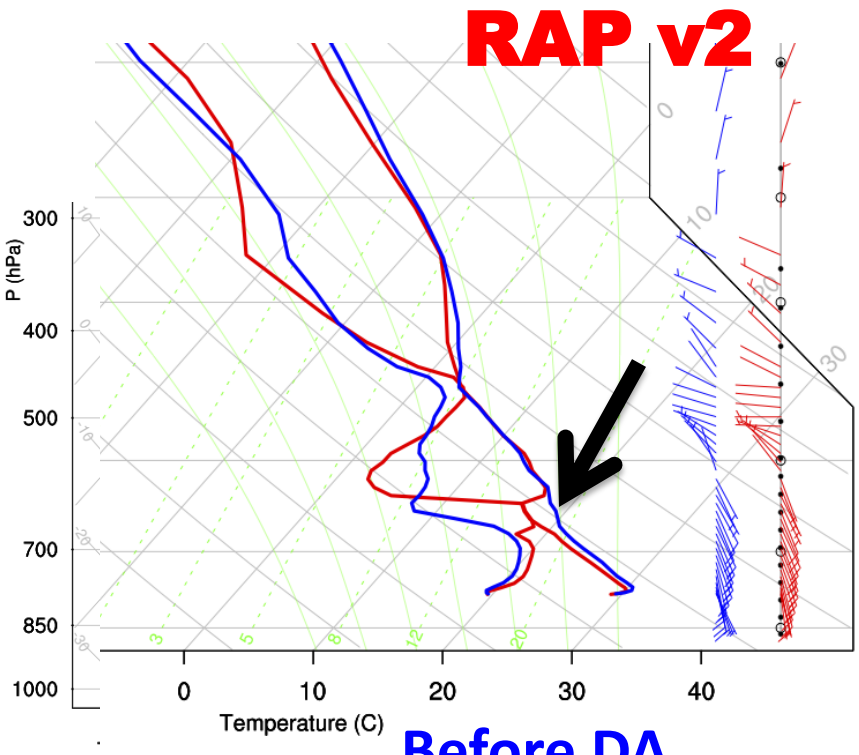
RAP Improved Cloud Analysis



Before Data Assim (DA)

After DA

NOT conserving θ_v



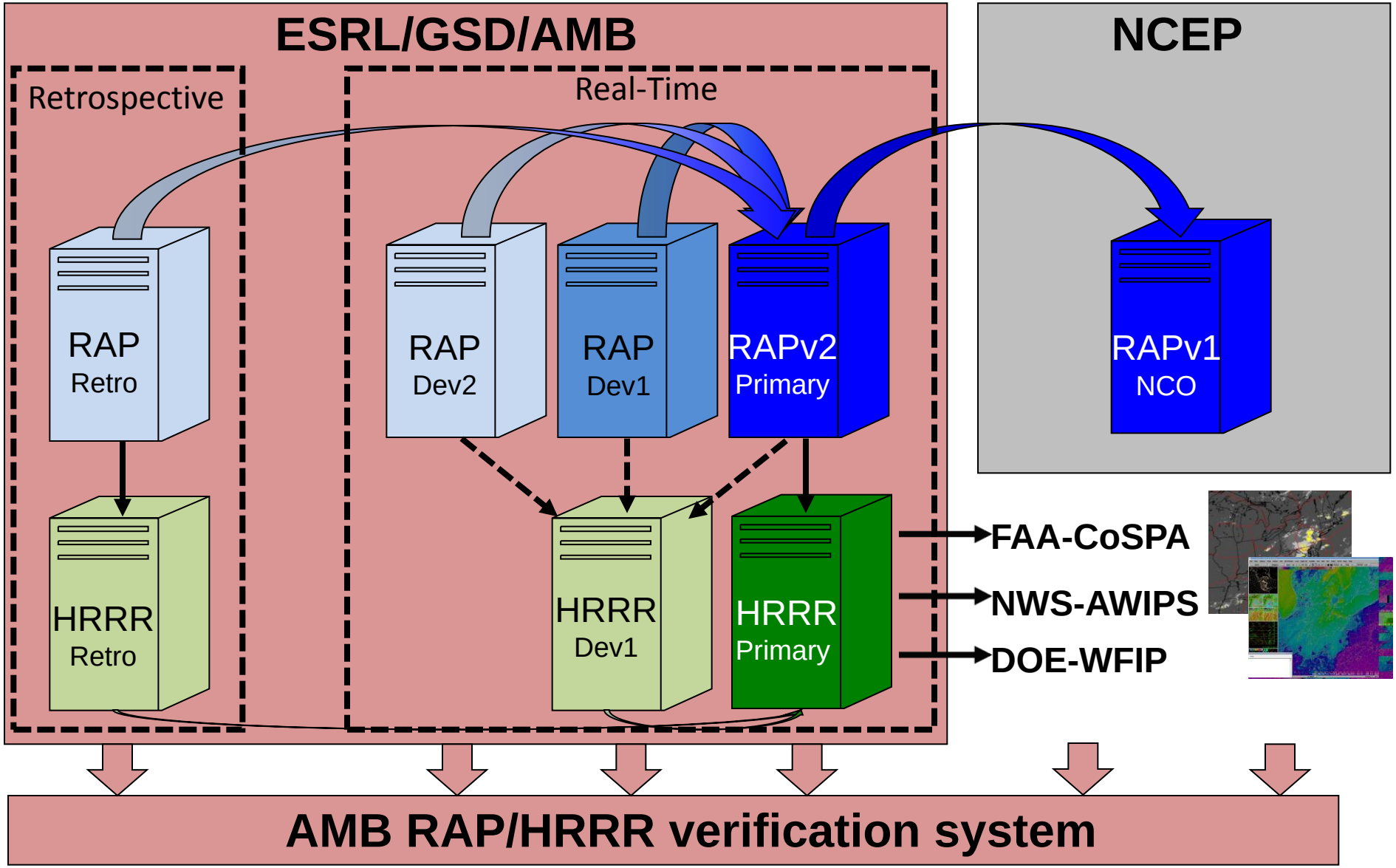
Before DA

After DA

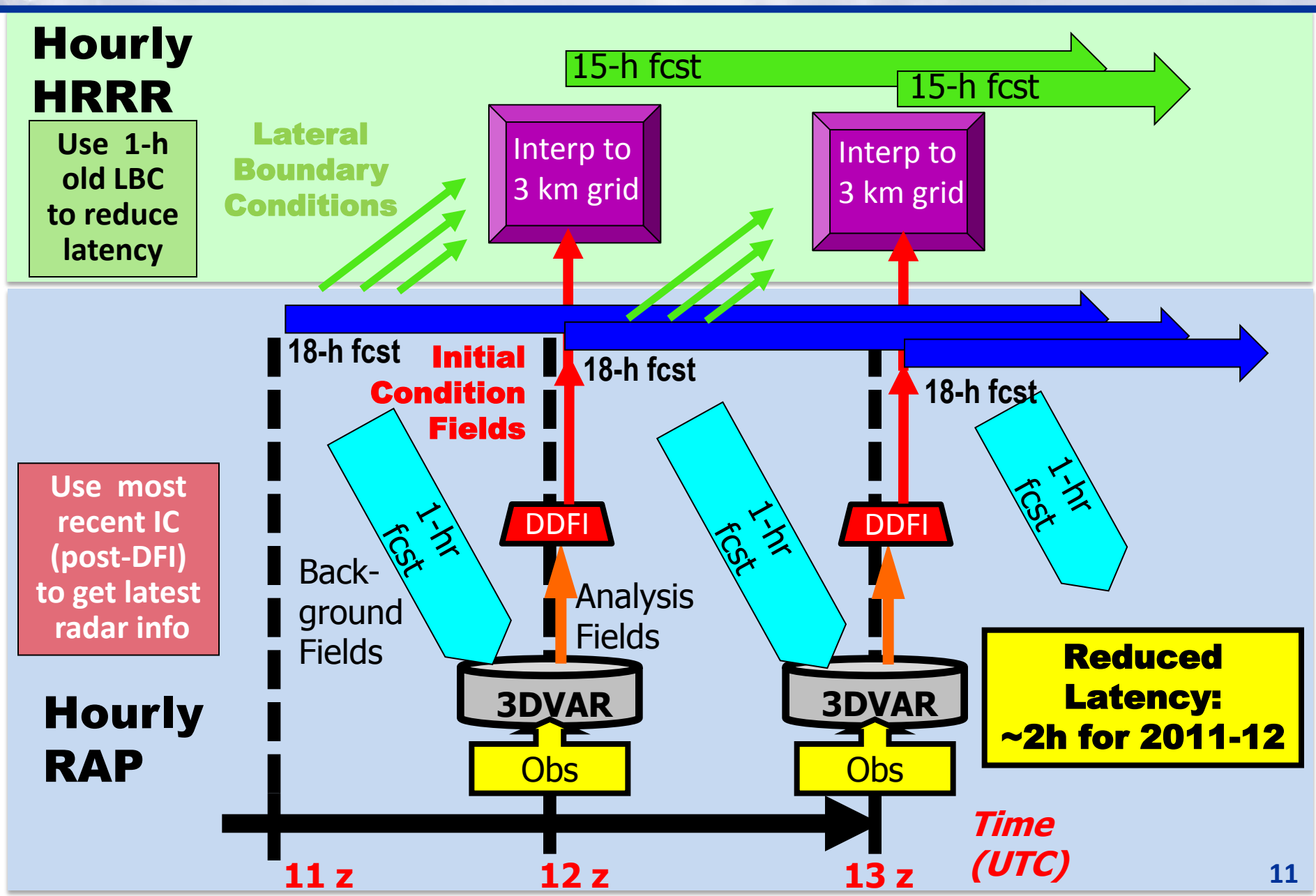
conserving θ_v

Assume virtual potential temperature is conserved when building clouds to avoid potential instability and convective development

Model Configurations



Hourly HRRR Initialization from RAP



RAP and HRRR Configurations

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	Sigma	GFS	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	Sigma	RAP	Hourly - RAP (no-cycle)

Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RAP	WRF-ARW v3.3.1+	GSI-3DVAR	Yes	RRTM/Goddard	Thompson	G3 + Shallow	MYJ	RUC
HRRR	WRF-ARW v3.3.1+	None: RAP I.C.	No	RRTM/Goddard	Thompson	None	MYJ	RUC

RAP and HRRR Resources

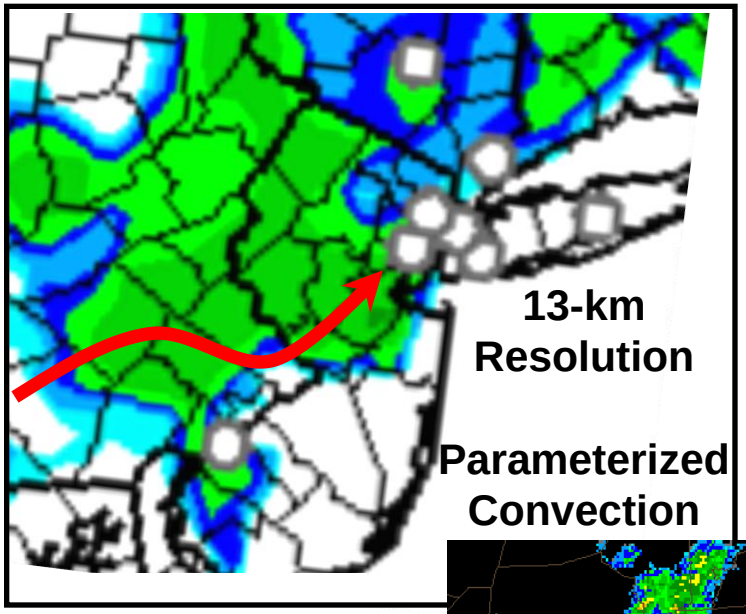
Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Height Lowest Level	Pressure Top	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	8 m	10 mb	Hourly (cycled)
HRRR	GSD	CONUS	1799 x 1059	3 km	50	8 m	20 mb	Hourly (no-cycle)

Model	Version	Initialized	Forecast Length	Run Time	# CPUs	Disk Space
RAP	WRFv3.3.1+	Hourly	18 hrs	~30 min	200	230 GB (per run)
HRRR	WRFv3.3.1+	Hourly	15 hrs	~50 min	1128	800 GB (per run)

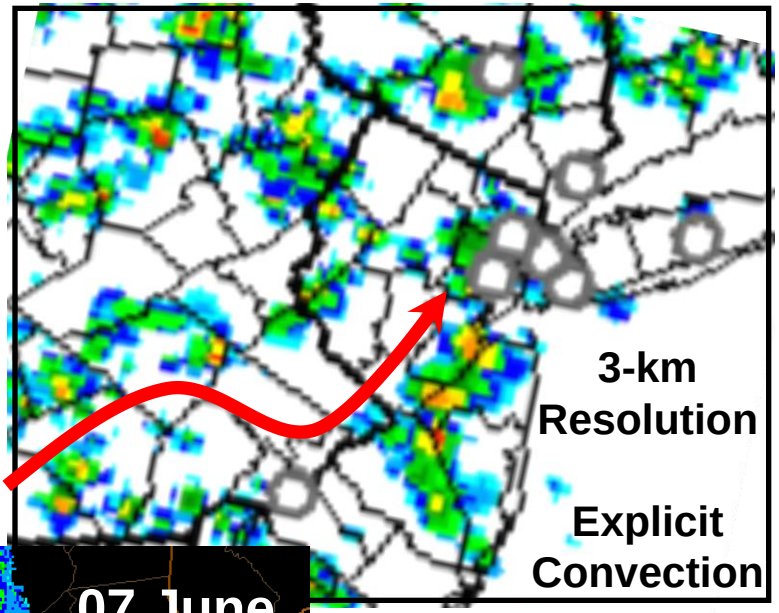
NOAA High-Performance Computer System	Number of Filesystems	Total Reserved Disk Space	CPU Type	Total Reserved CPUs	Performance Increase
Jet (current)	4	150 TB	Intel Nehalem	1736	-
Zeus (new)	2	230 TB	Intel Westmere	2000-4000	30%

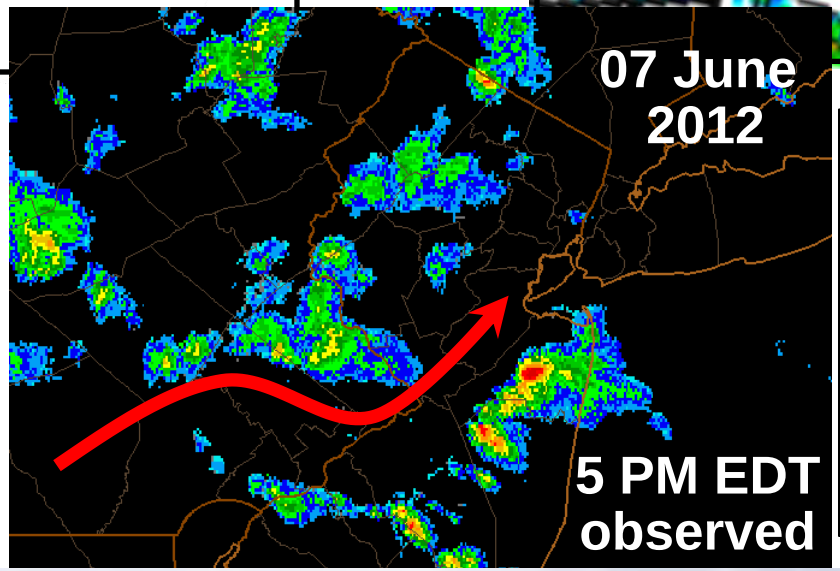
Key Advantage of 3-km HRRR

13-km 6hr forecast



HRRR 6hr forecast





NO STORM STRUCTURE

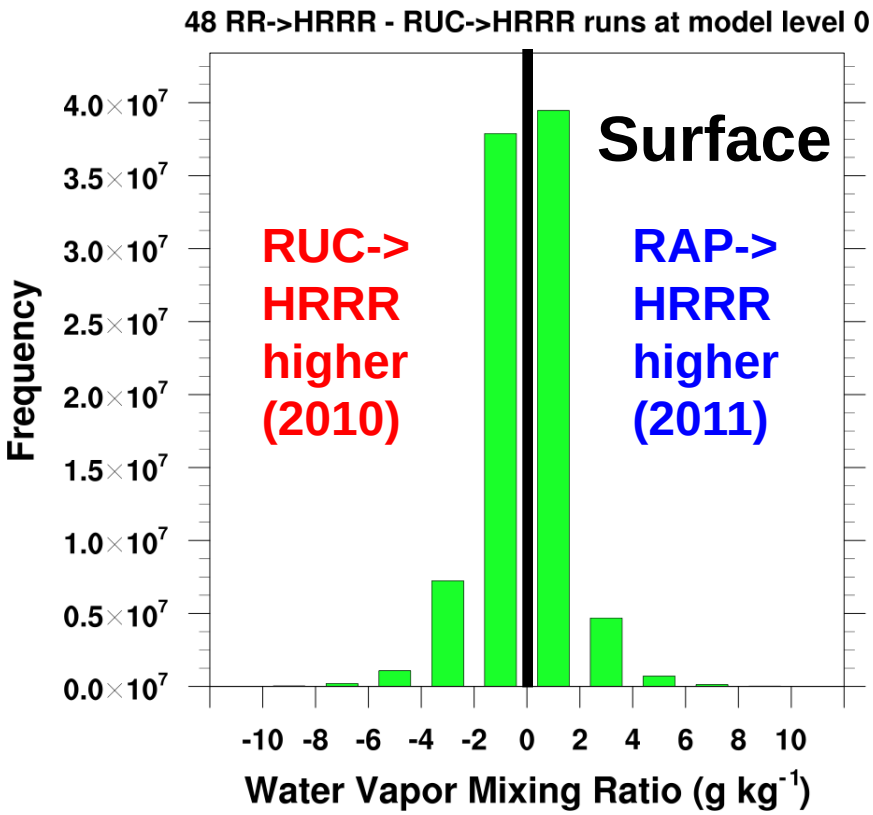
NO ESTIMATE OF PERMEABILITY

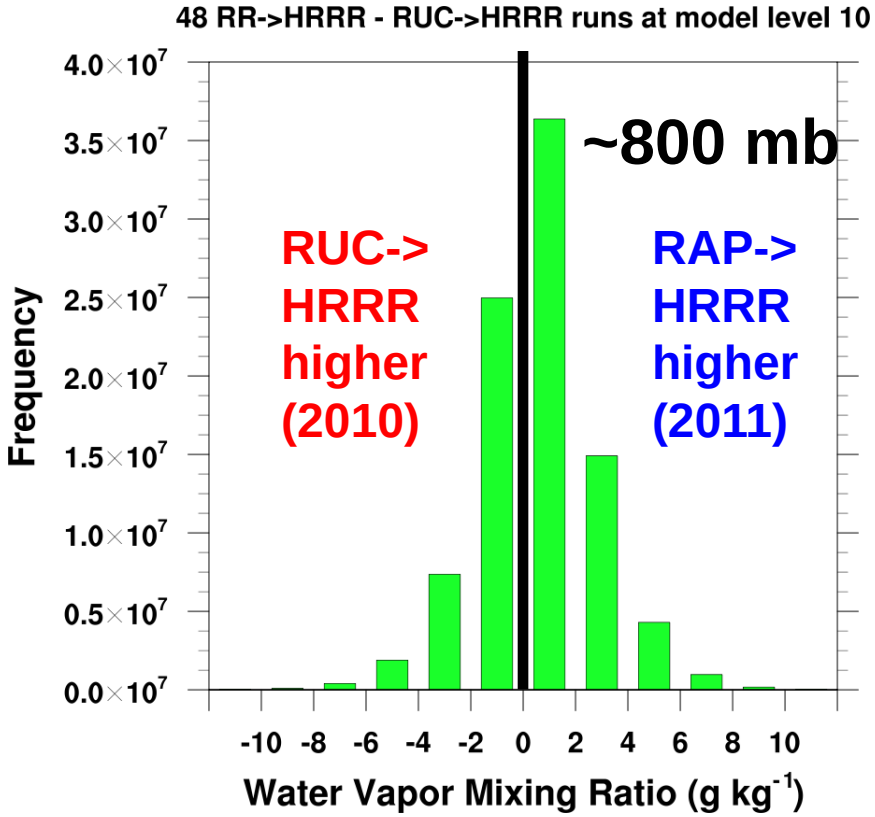
ACCURATE STORM STRUCTURE

ACCURATE ESTIMATE OF PERMABILITY

HRRR Water Vapor Histograms

CONUS
11-22 August 2011
0 hr Analysis on 3km grid





Moisture differences large enough to affect convective forecasts

HRRR Forecast Behavior

2011

(1) **High bias** in convection over **eastern US**

(2) **False alarms**

(3) **Lead** in convective initiation (early AM runs)

(4) **Difficulty** maintaining **mesoscale convective systems**

(5) **Reflectivity biases** in snow and convective storms

RAP/HRRR Model Development and Evaluation

2012 Targets

(1) **Lower peak bias** in convection over **eastern US**

(2) **Fewer false alarms**

(3) **Improved timing** of convective initiation

(4) **More success** maintaining **mesoscale convective systems**

(5) **More realistic reflectivity**

RAP/HRRR Changes for 2012

Red = Changes in current RAP/HRRR effective before 09 March 2012

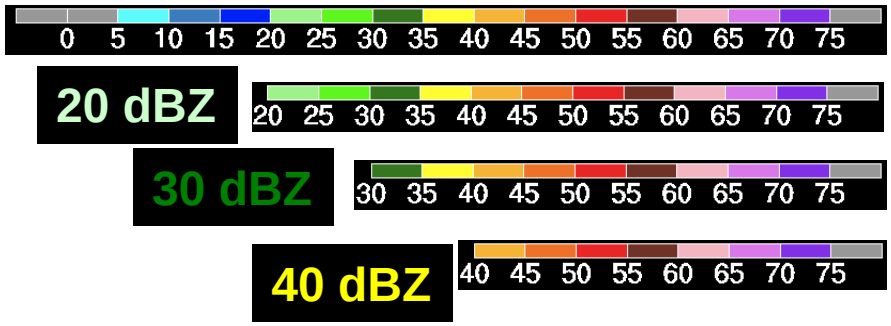
	Model	Data Assimilation
RAP (13 km)	WRFv3.3.1+ Physics changes (convection, microphysics, land-surface, PBL) Numerics changes (w-damp upper bound conditions, 5th-order vertical advection) MODIS land use, fractional 30→10 min shortwave radiation New reflectivity diagnostic	Soil adjustment, Temp-dep radar-hydrometeor building PW assim mods Cloud assim mods Tower/nacelle/sodar observations GLD360 lightning GSI merge with trunk Radial wind assim
HRRR (3 km)	WRFv3.3.1+, Physics changes (microphysics, land-surface, PBL) Numerics changes (w-damp upper bound conditions, 5th-order vertical advection) MODIS land use, fractional 30→05 min shortwave radiation New reflectivity diagnostic	3 km/15 min reflect assim 3 km radial wind assim 3 km cloud cycling 3 km land-surface cycling

RAP/HRRR Verification System

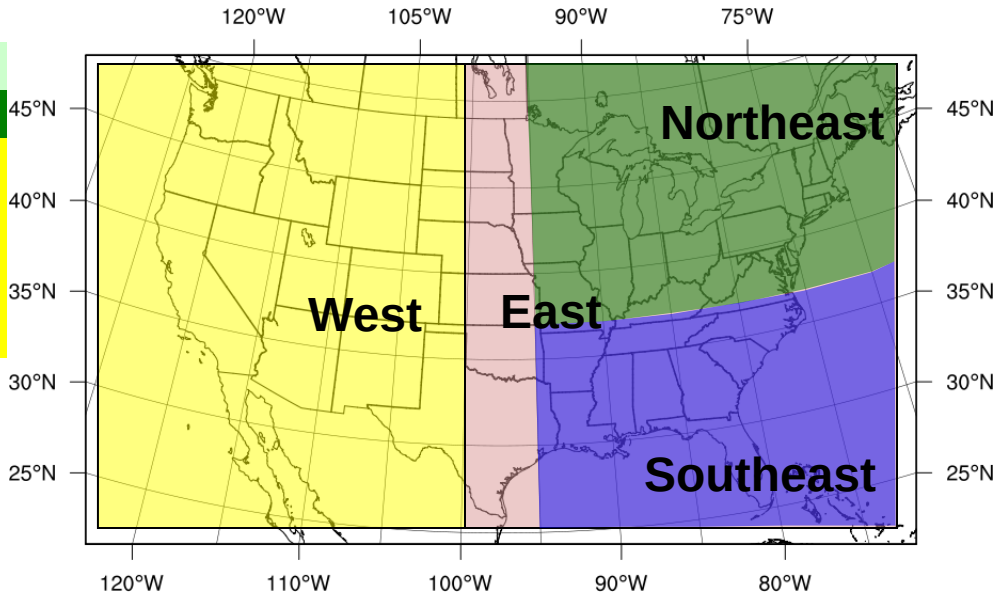
Intensity Threshold

VIP** Level	Echo Intensity	Precipitation Intensity	Rainfall Rate (in/hr) Stratiform	Rainfall Rate (in/hr) Convective	Reflectivity in (dBZ)
1	Weak	Light	Less Than 0.1	Less Than 0.2	Min. Signal - 30
2	Moderate	Moderate	0.1 - 0.5	0.2 - 1.1	31 - 40
3	Strong	Heavy	0.5 - 1.0	1.1 - 2.2	41 - 45
4	Very Strong	Very Heavy	1.0 - 2.0	2.2 - 4.5	46 - 50
5	Intense	Intense	2.0 - 5.0	4.5 - 7.1	51 - 57
6	Extreme	Extreme	More Than 5.0	More Than 7.1	> 57

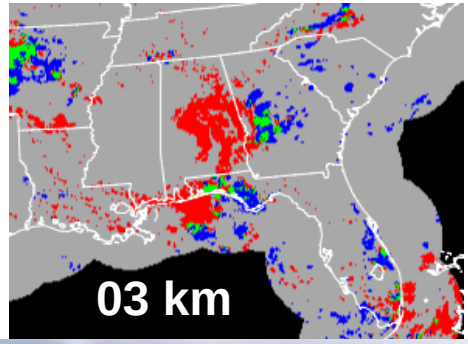
Highest precipitation top in area in hundreds of feet MSL (45,000 feet MSL).

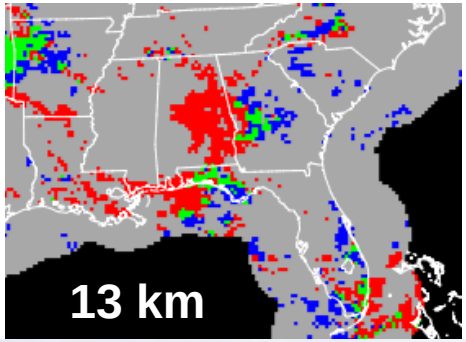


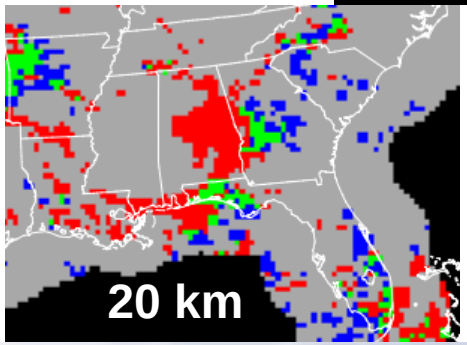
Domain

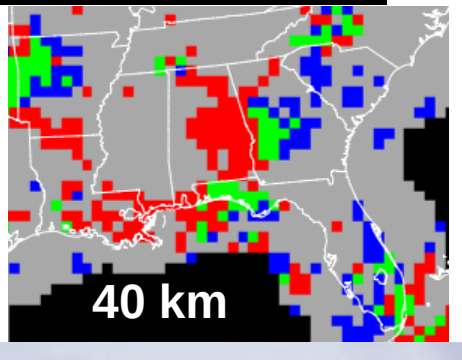


Resolution of Verification

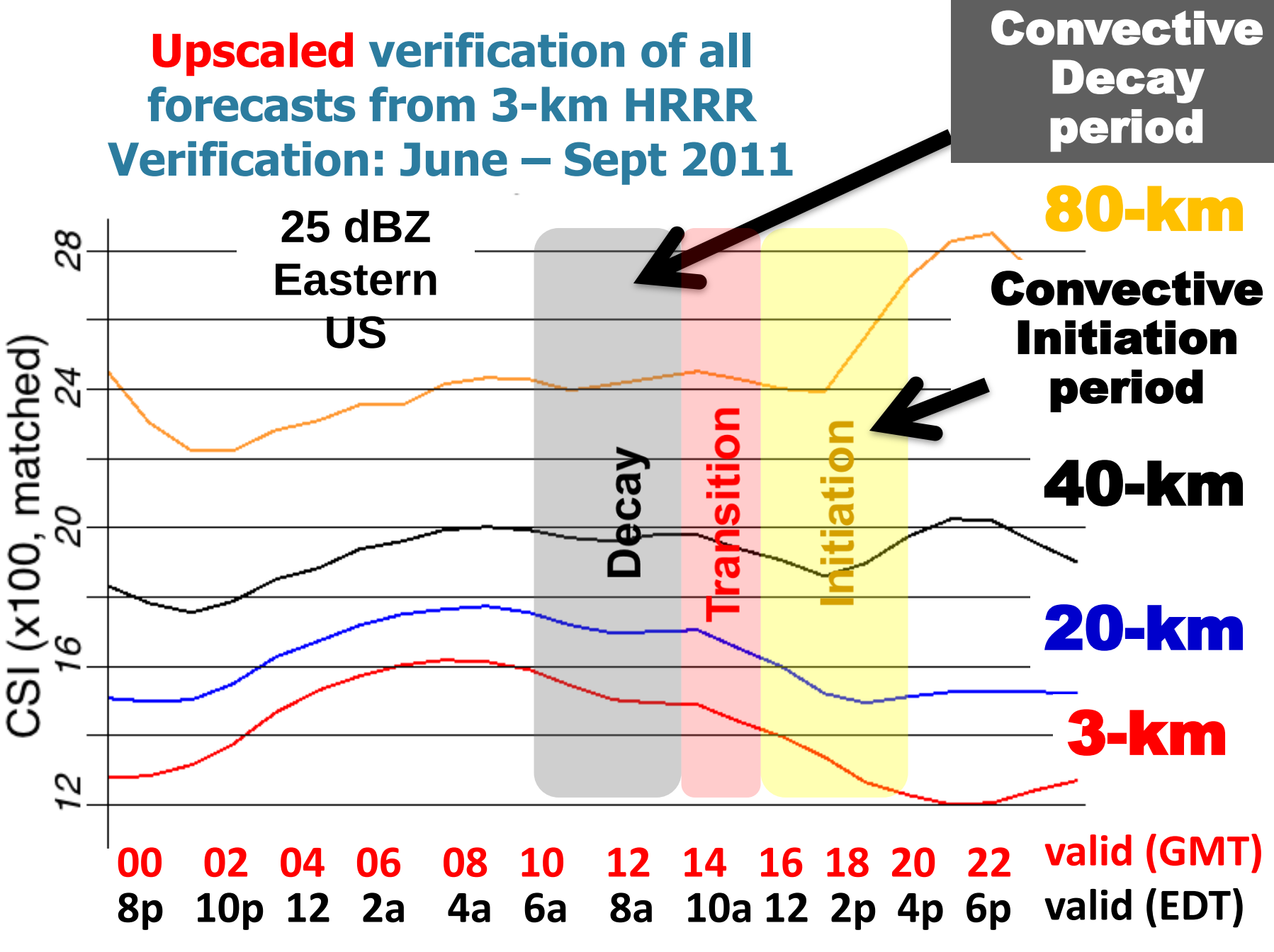








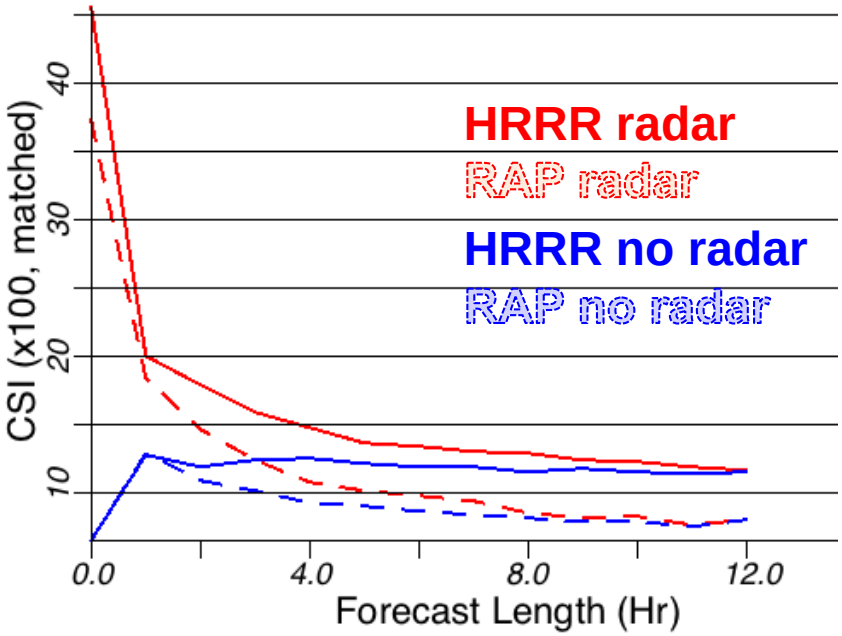
Upscaled verification of all forecasts from 3-km HRRR
Verification: June – Sept 2011



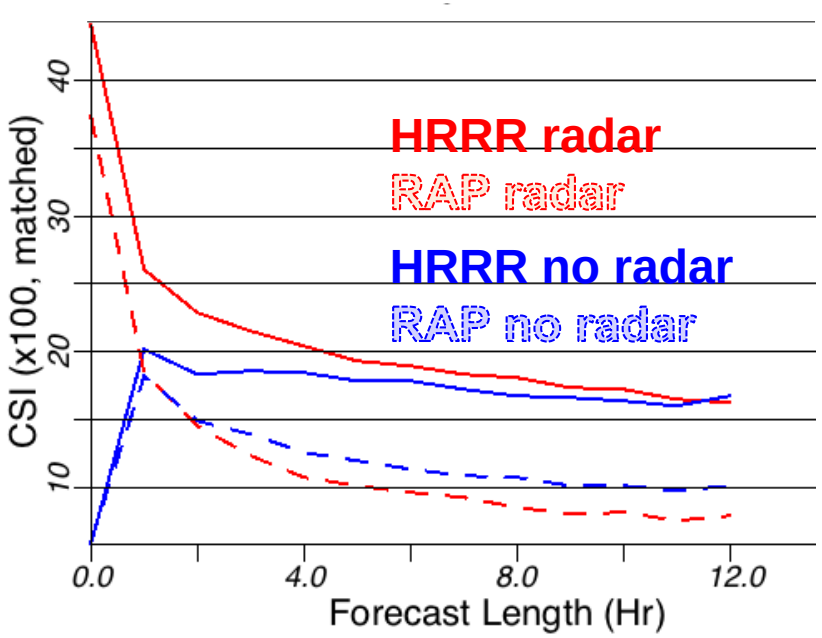
RAP/HRRR Reflect Assim Verif

Eastern US, Reflectivity > 25 dBZ
11-21 August 2011

CSI 13 km



CSI 40 km



- 3km HRRR forecasts improve upon RAP 13km forecasts, especially at coarser scales → much better upscaled skill
- Radar data assimilation via DDFI adds skill at both 13km and 3km

HRRR Retrospective Runs

Compare **real-time HRRR runs (2011 configuration)** vs
HRRR with recent changes (2012 configuration)
using 2011 retrospective periods

29 May – 12 Jun 2011 (160 matched runs)
11 Aug – 22 Aug 2011 (135 matched runs)

Execute 2011 retrospective periods with 2012 model runs every other hour (even hours only) for 12 runs per day

Total of 295 matched runs (cases)
Approximately 10x sample size for statistical significance

Approximately 22-24 matched runs for each initialization hour

HRRR Aug Retro Verification

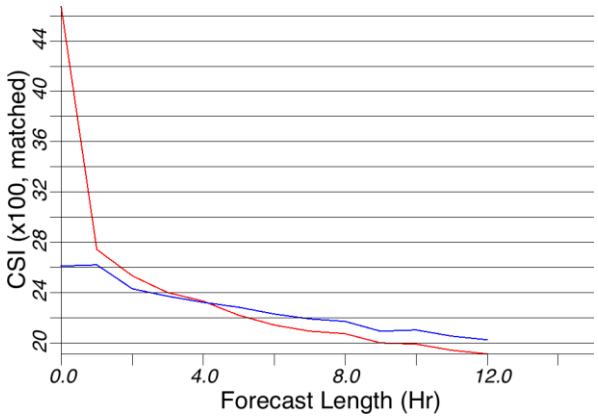
Reflectivity Eastern US
135 Runs 11-22 August 2011

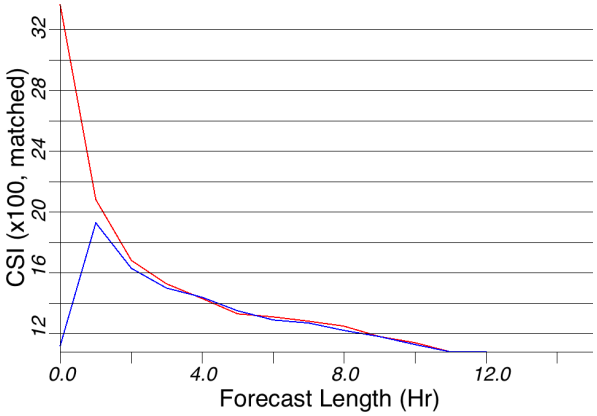
HRRR 2011
HRRR 2012

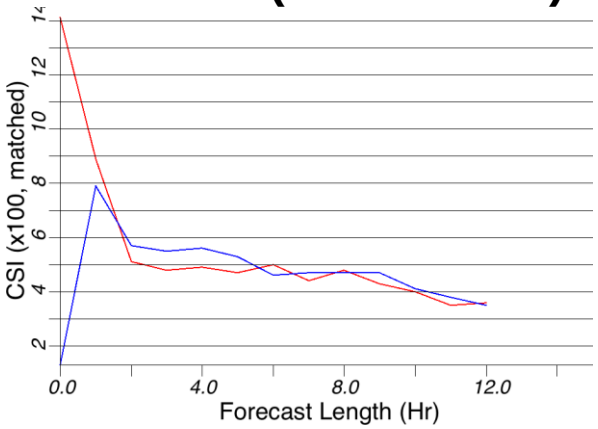
Reduced high bias in first 6 hrs

20 dBZ (~Echo Top Threshold) | 30 dBZ (~VIP level 2) | 40 dBZ (~VIP level 3)

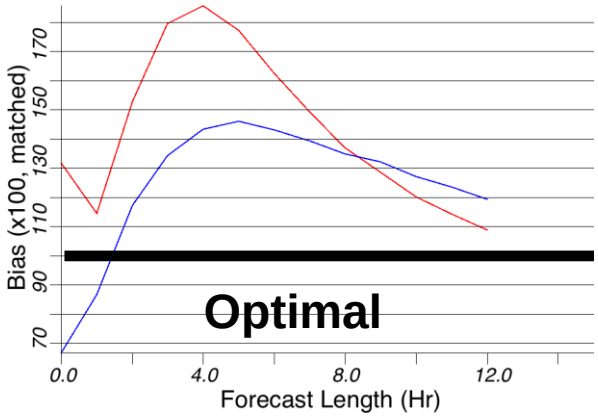
CSI 40 km

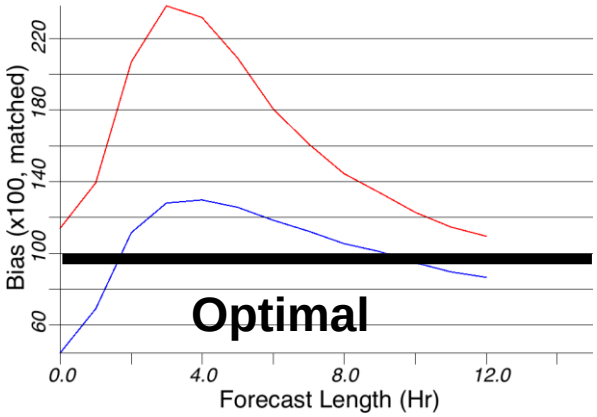


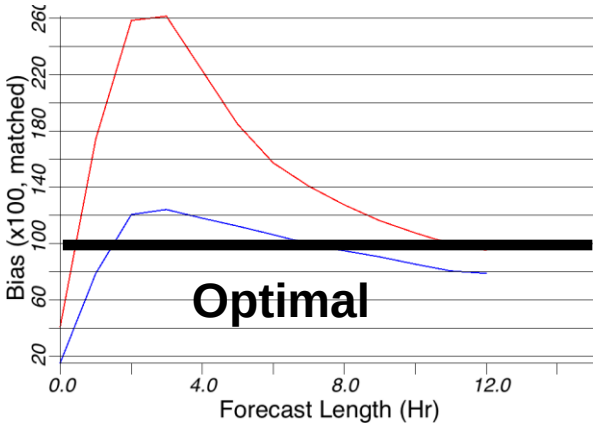




BIAS 03 km





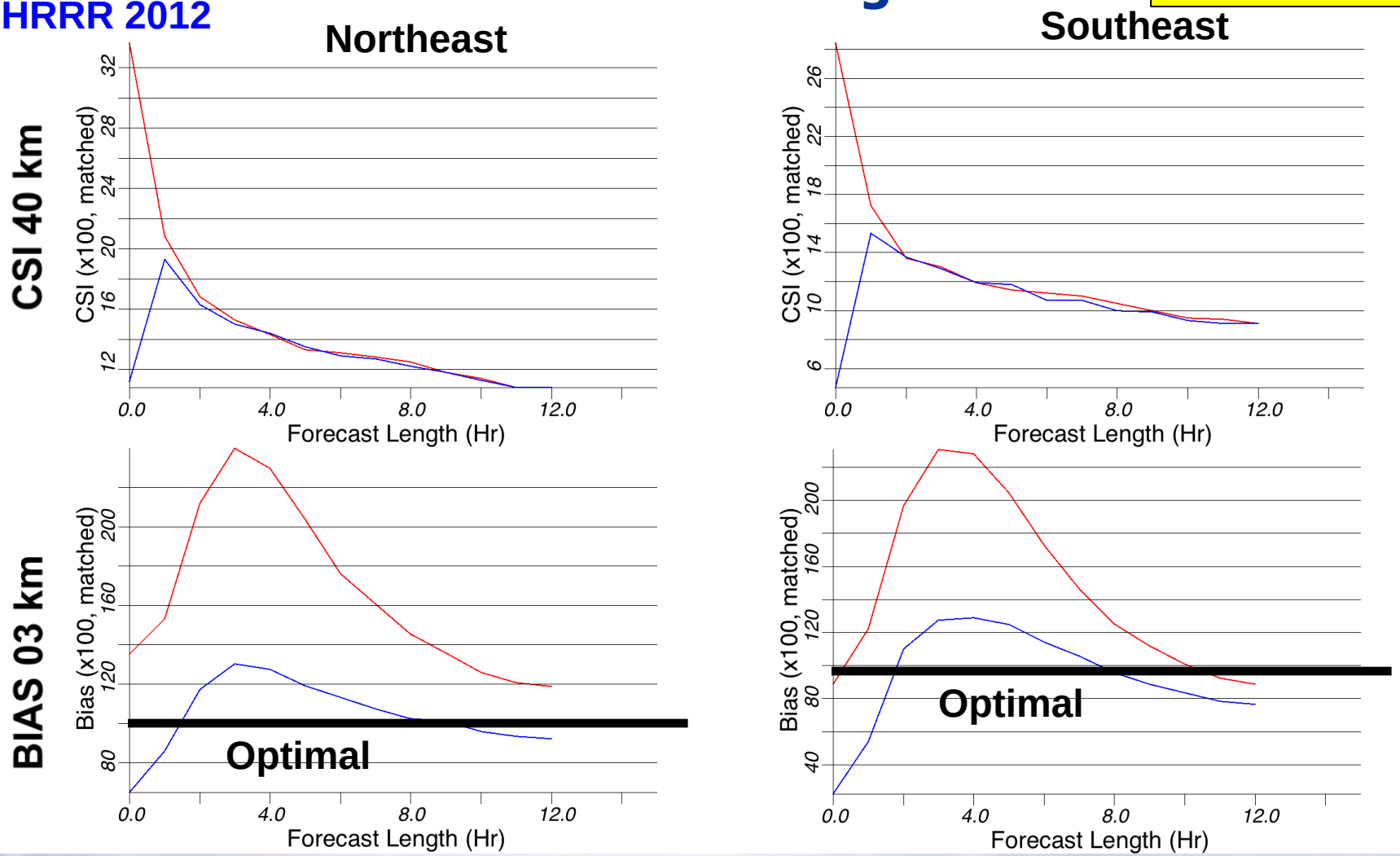


HRRR Aug Retro Verification

Reflectivity ≥ 30 dBZ
135 cases 11-22 August 2011

Reduced high bias first 6 hrs

HRRR 2011
HRRR 2012



HRRR June Retro Verification

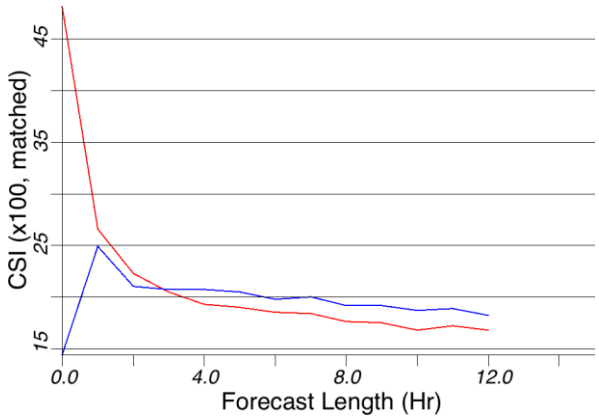
Reflectivity Eastern US
160 Runs 29 May – 12 June 2011

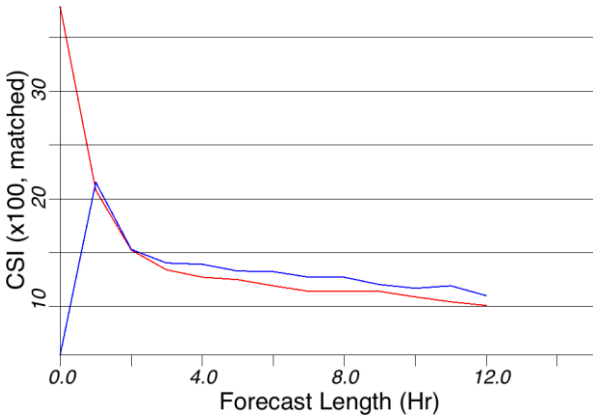
HRRR 2011
HRRR 2012

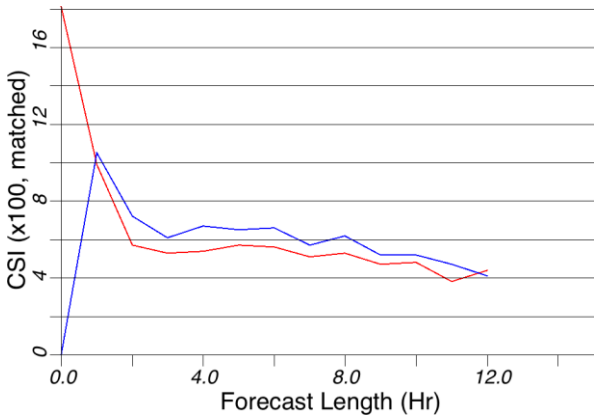
Reduced high bias in first 6 hrs and improved CSI

20 dBZ (~Echo Top Threshold) 30 dBZ (~VIP level 2) 40 dBZ (~VIP level 3)

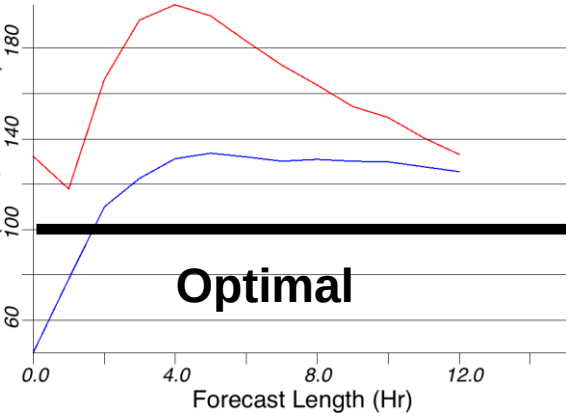
CSI 40 km

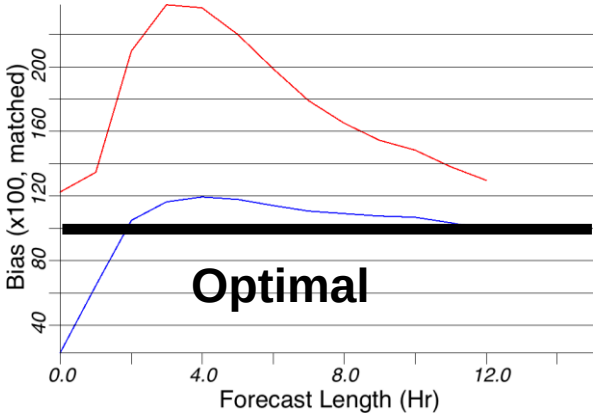


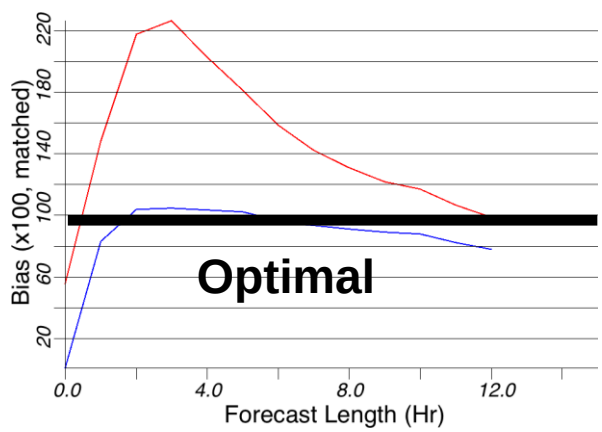




BIAS 03 km







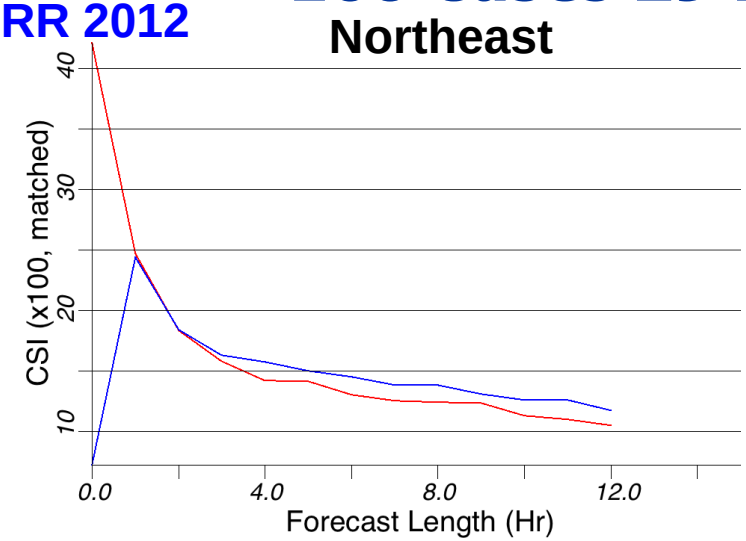
HRRR June Retro Verification

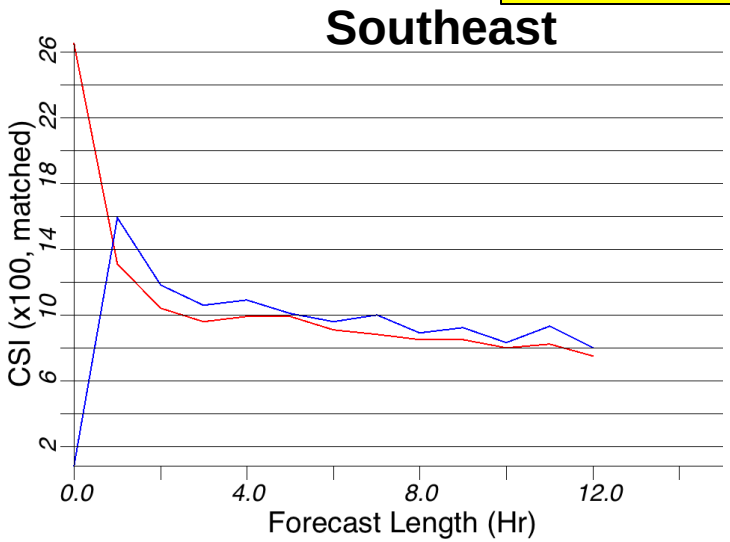
Reflectivity ≥ 30 dBZ
160 Cases 29 May – 12 June 2011

Reduced bias
Improved CSI

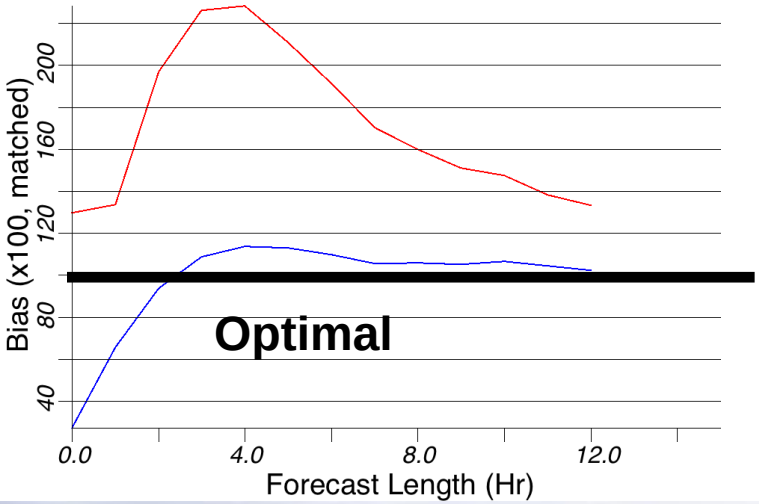
HRRR 2011
HRRR 2012

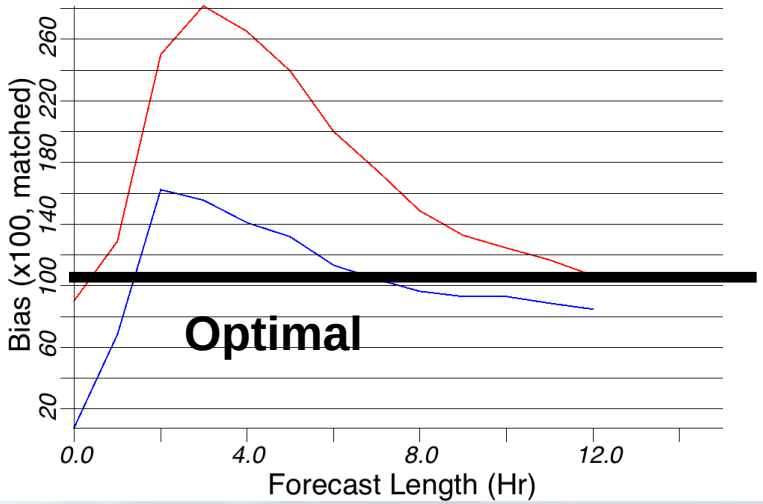
CSI 40 km





BIAS 03 km



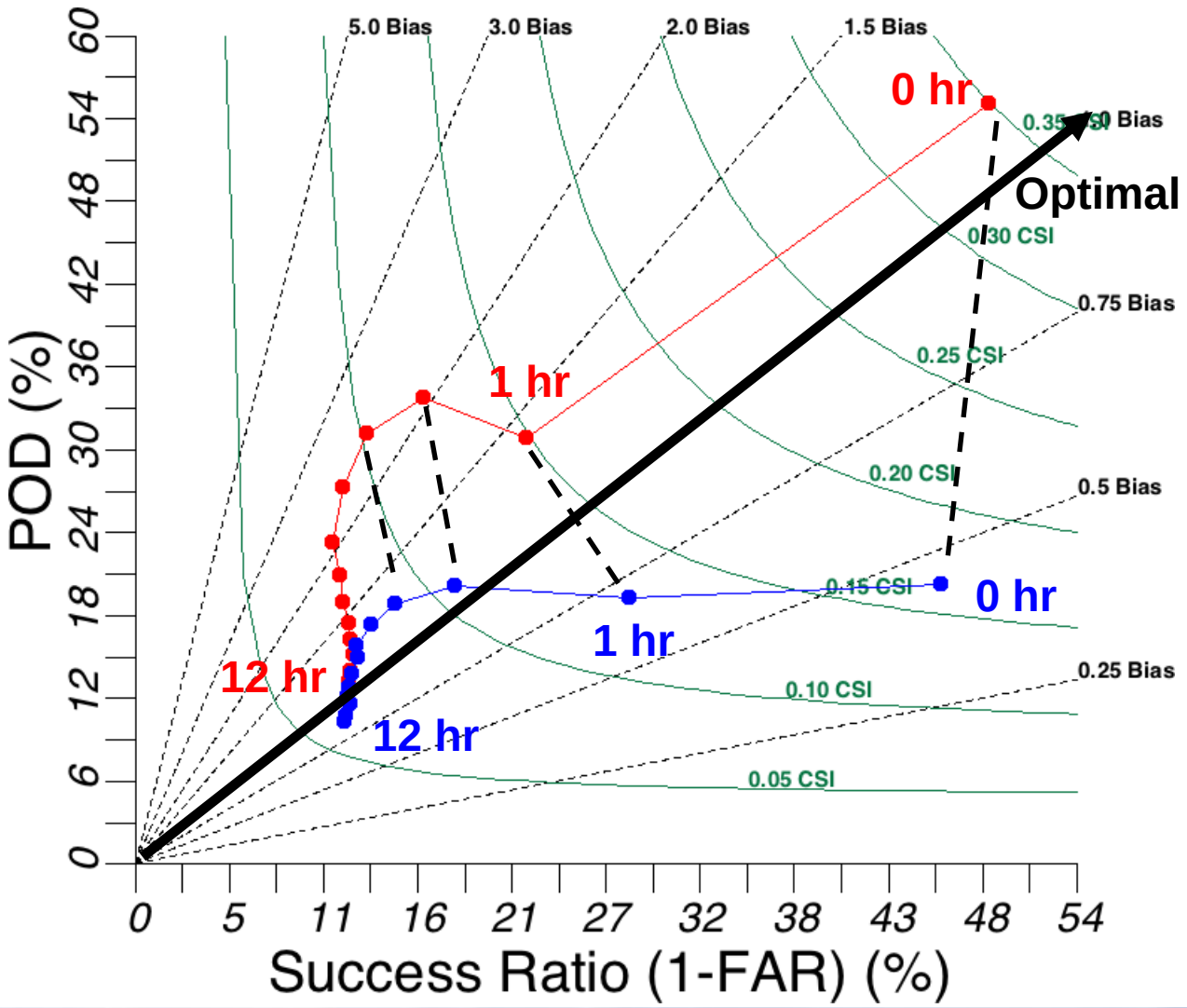


HRRR August Retro Verification

Reflectivity ≥ 30 dBZ **03km Eastern US** **11-22 August 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs

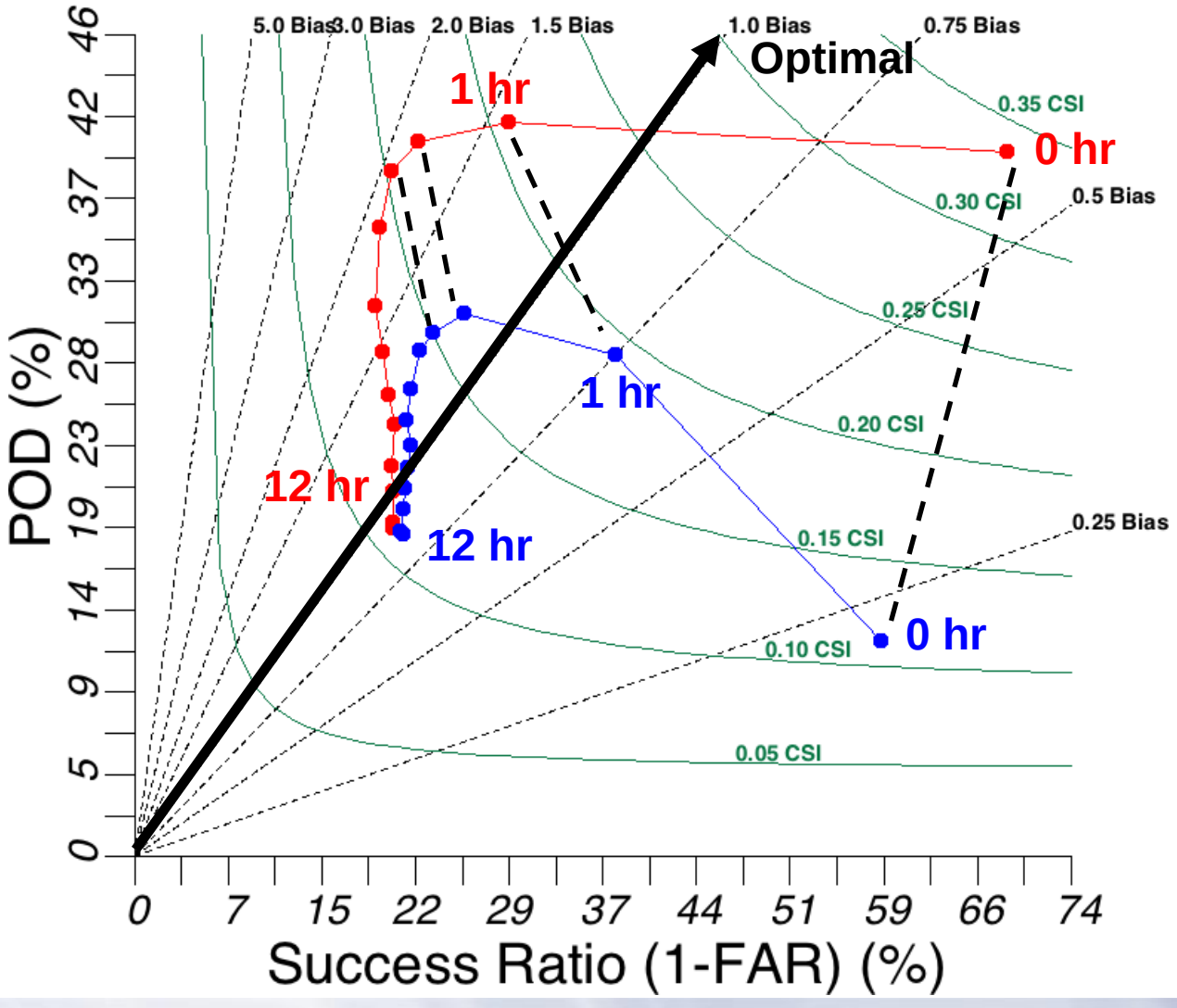


HRRR August Retro Verification

Reflectivity ≥ 30 dBZ **40km Eastern US** **11-22 August 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs

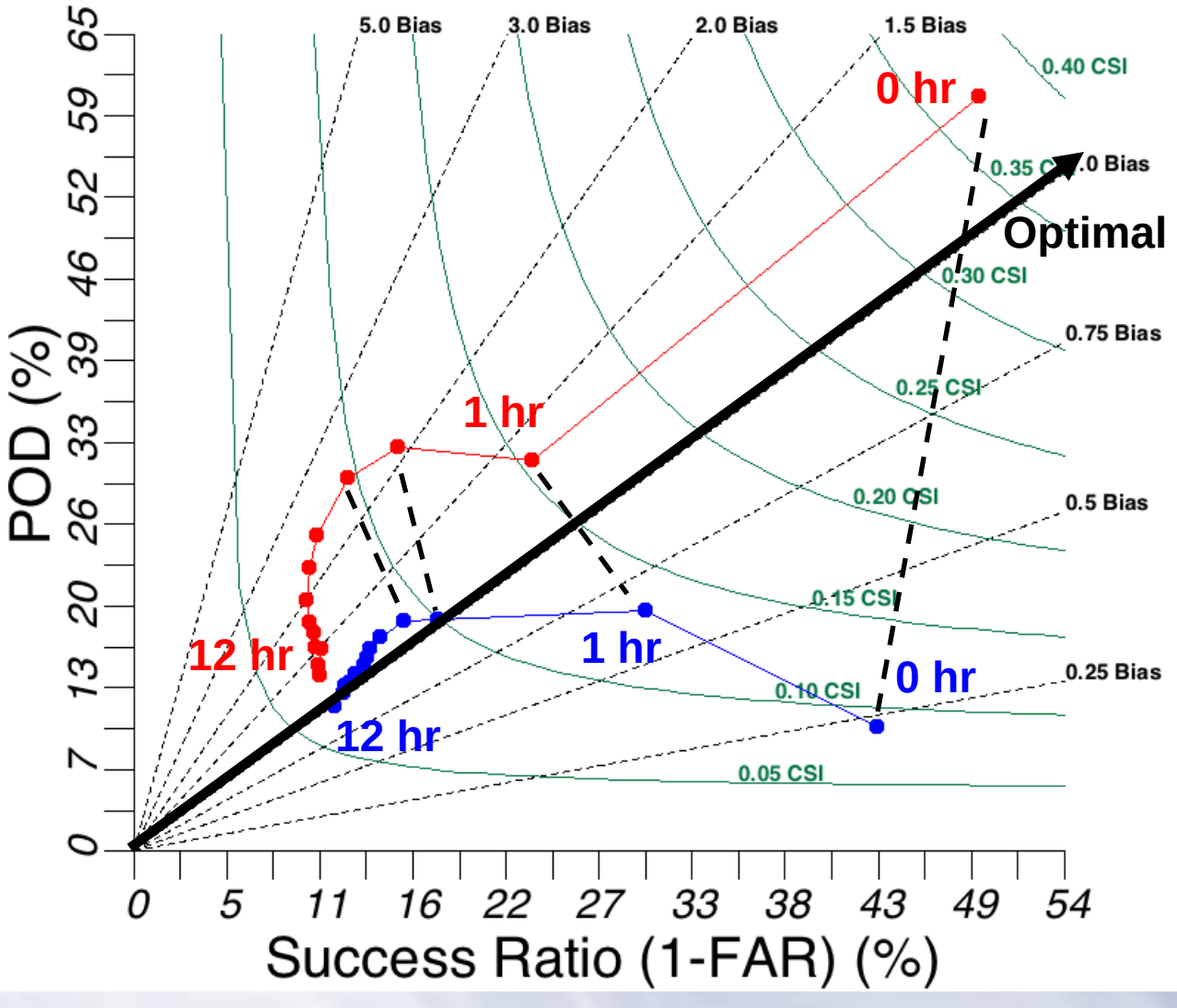


HRRR June Retro Verification

Reflectivity ≥ 30 dBZ **03km** **Eastern US** **29 May – 12 June 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs and improved CSI



HRRR June Retro Verification

Reflectivity ≥ 30 dBZ **40km** **Eastern US** **29 May – 12 June 2011**

HRRR 2011 (real-time)
HRRR 2012 (retro)

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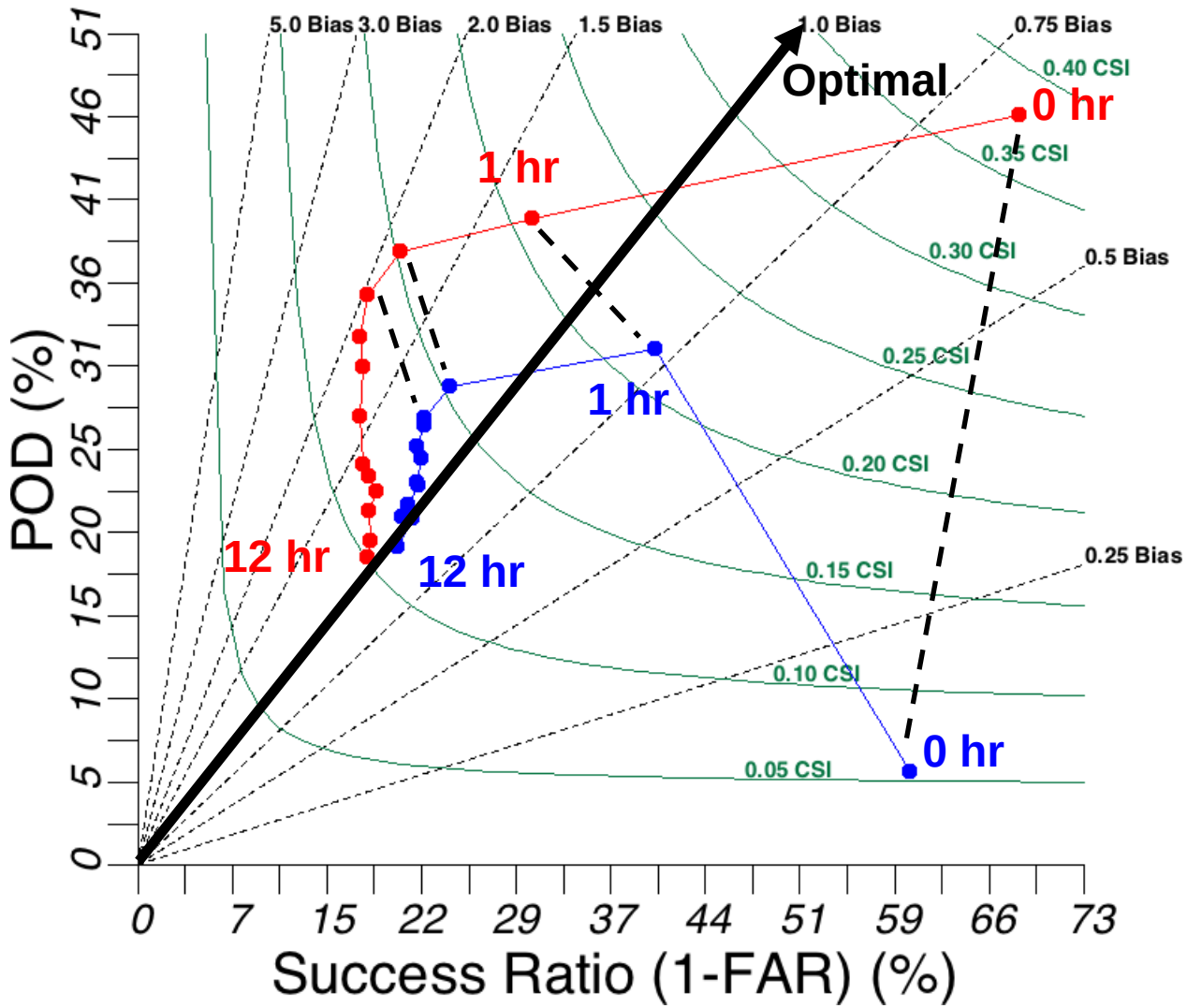
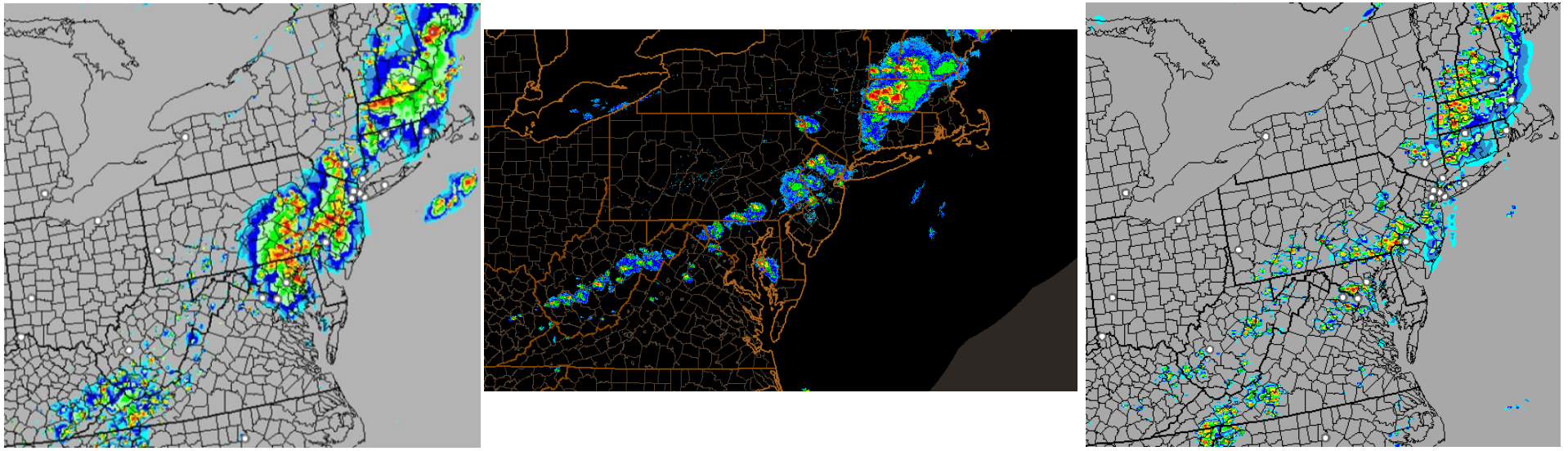


HRRR Retro Case Studies

HRRR 4hr fcst 2011 Real-Time

20z 01 June 2011 Observations

HRRR 4hr fcst 2012 Version



Composite Reflectivity (dBZ)

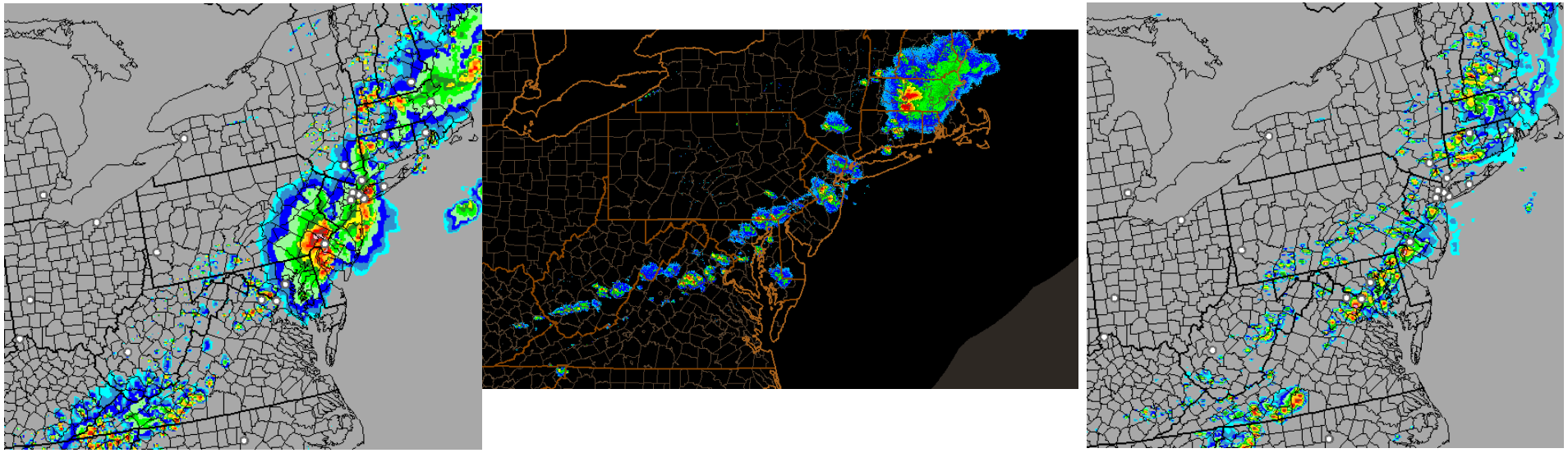
Large reduction in false alarm (excessive) convection
Improved structure to broken convective line

HRRR Retro Case Studies

HRRR 5hr fcst 2011 Real-Time

21z 01 June 2011 Observations

HRRR 5hr fcst 2012 Version

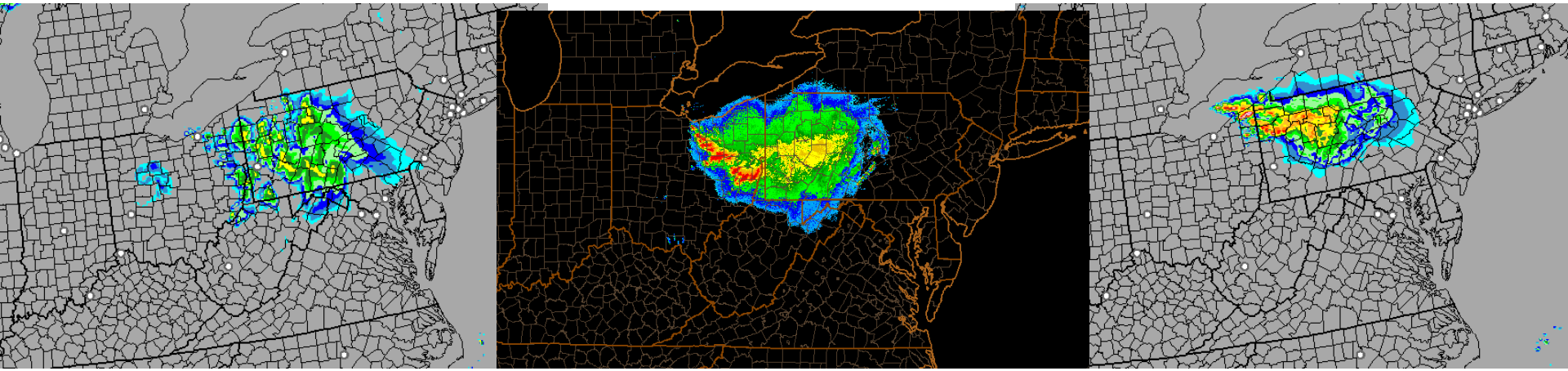


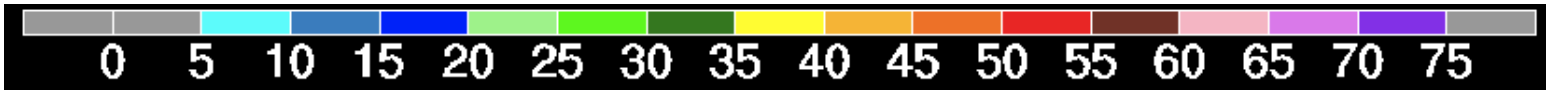
Composite Reflectivity (dBZ)

Large reduction in false alarm (excessive) convection
Improved structure to broken convective line

HRRR Retro Case Studies

HRRR 7hr fcst 2011 Real-Time | **15z 07 June 2011 Observations** | **HRRR 7hr fcst 2012 Version**



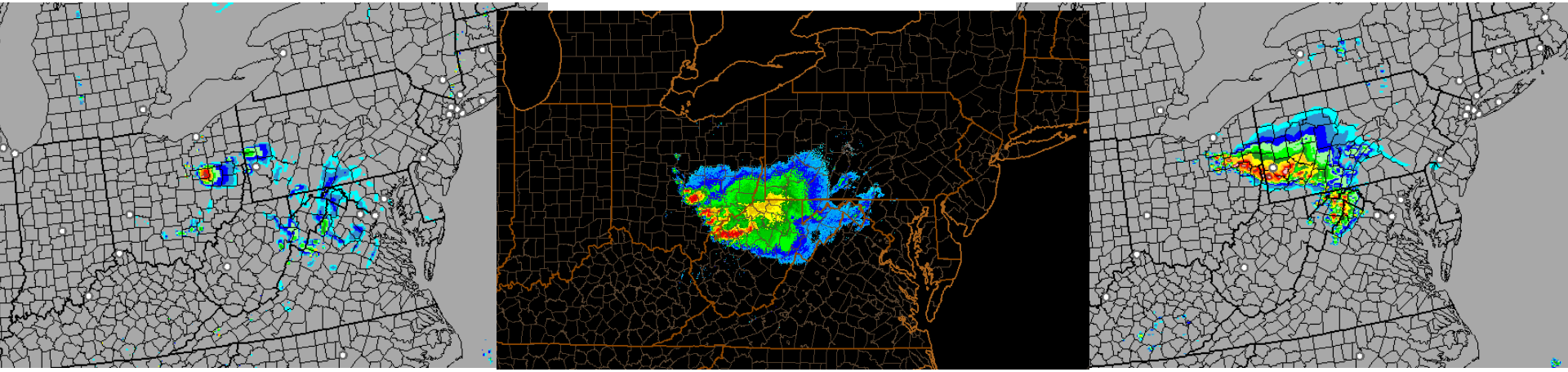


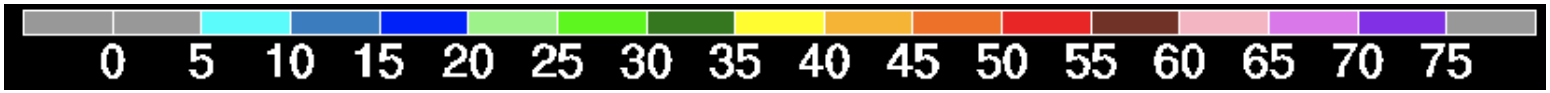
Composite Reflectivity (dBZ)

Improved mesoscale convective system (MCS) maintenance

HRRR Retro Case Studies

HRRR 10hr fcst 2011 Real-Time | **18z 07 June 2011 Observations** | **HRRR 10hr fcst 2012 Version**





Composite Reflectivity (dBZ)

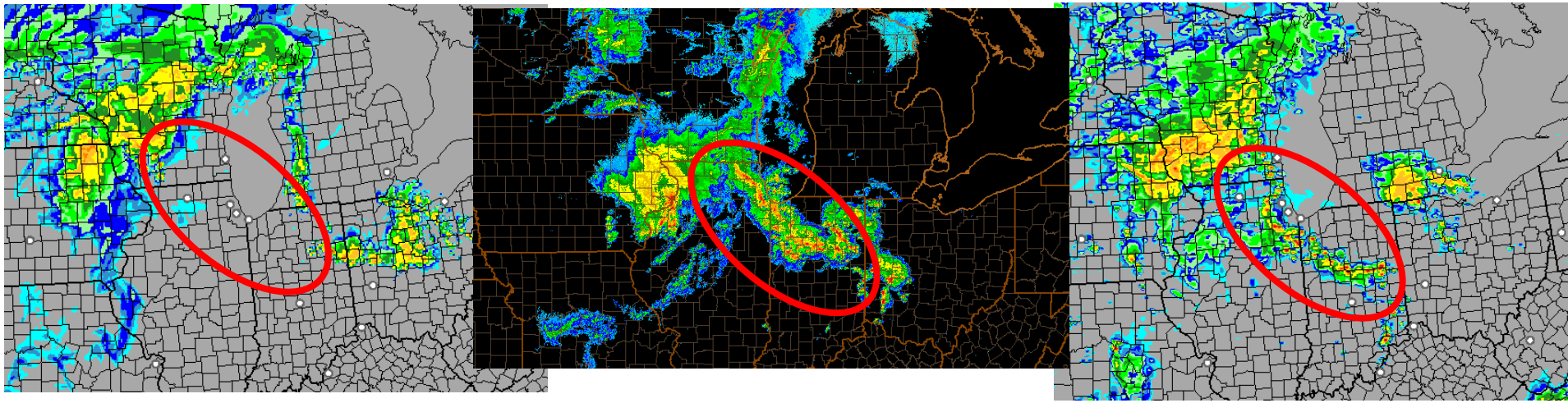
Improved mesoscale convective system (MCS) maintenance

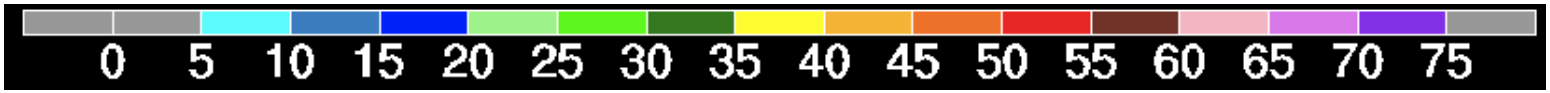
HRRR Retro Case Studies

HRRR 10hr fcst 2011 Real-Time

10z 10 June 2011 Observations

HRRR 10hr fcst 2012 Version



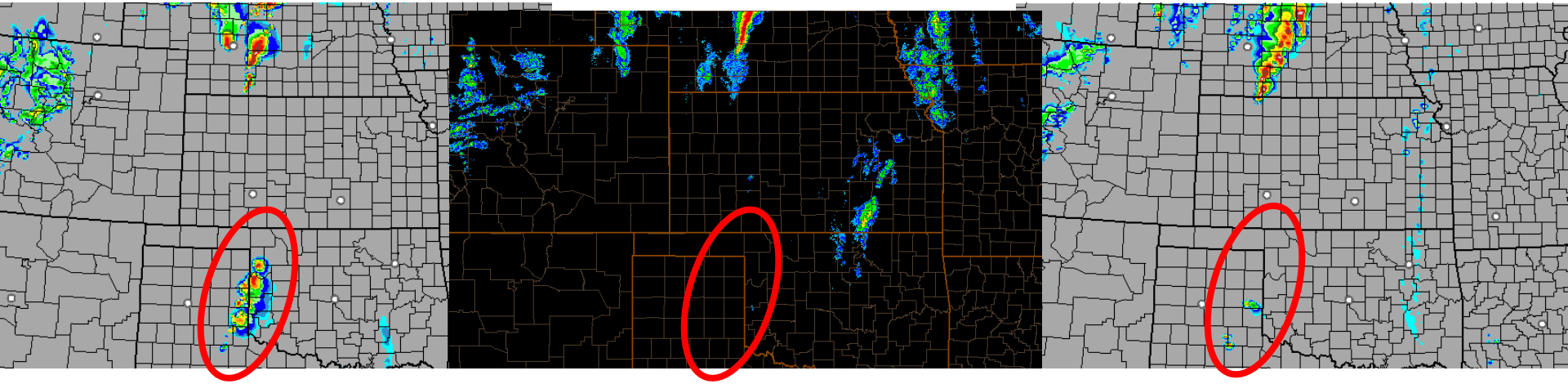


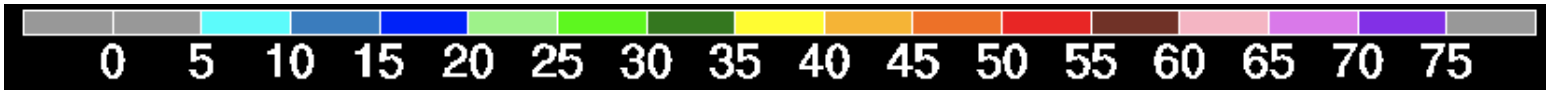
Composite Reflectivity (dBZ)

Improved timing of convective initiation

HRRR Retro Case Studies

HRRR 8hr fcst 2011 Real-Time | **00z 31 May 2011 Observations** | **HRRR 8hr fcst 2012 Version**





Composite Reflectivity (dBZ)

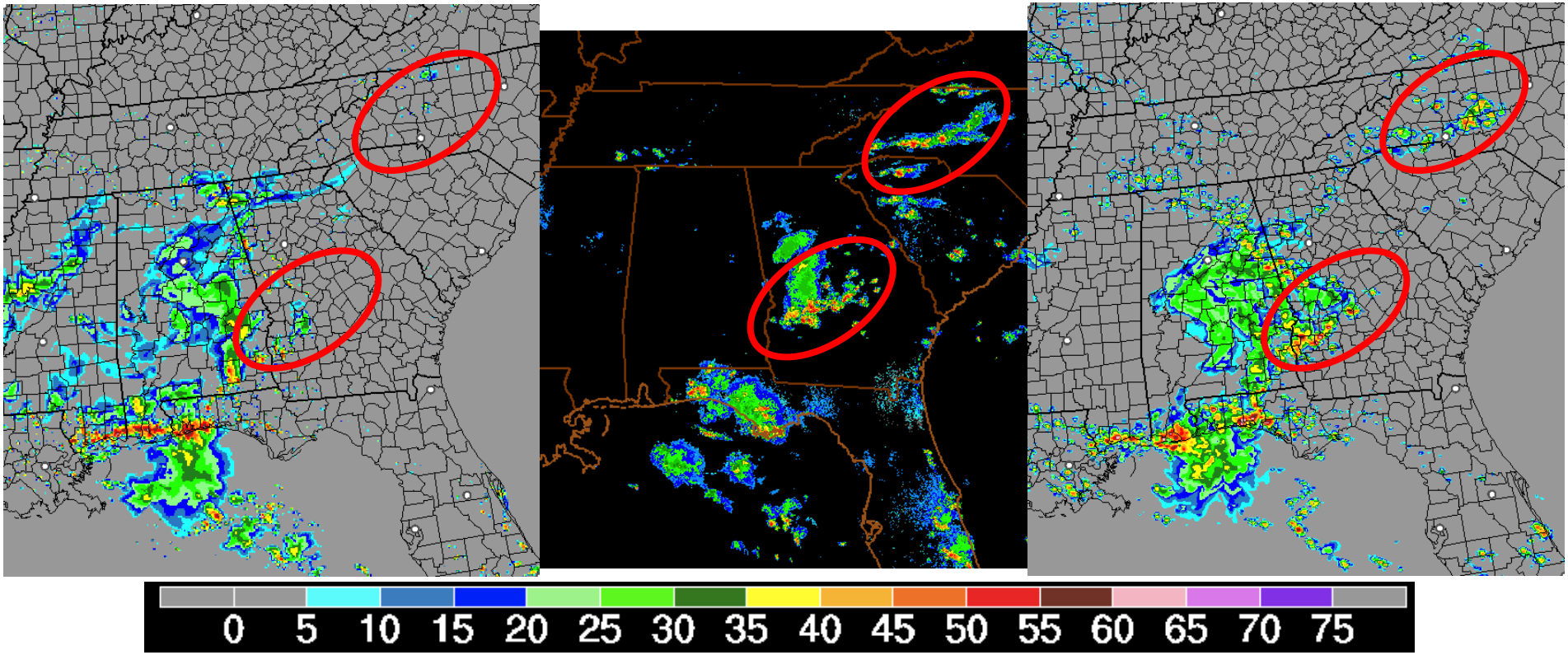
Reduction in false alarm convective initiation

HRRR Retro Case Studies

HRRR 8hr fcst 2011 Real-Time

20z 11 Aug 2011 Observations

HRRR 8hr fcst 2012 Version



Composite Reflectivity (dBZ)

Improved convective initiation

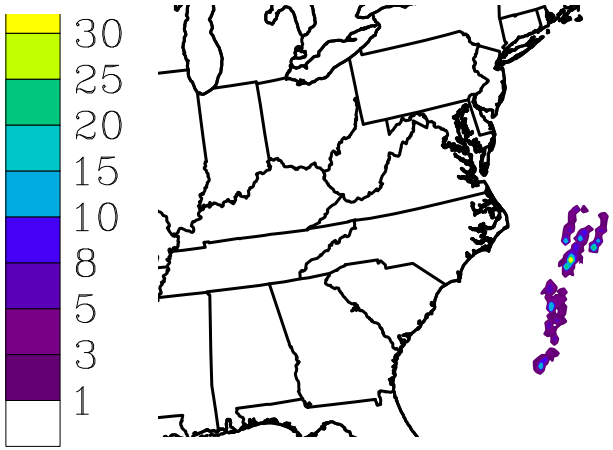
RAP New Observation Sources

RAP v2 new observation sources

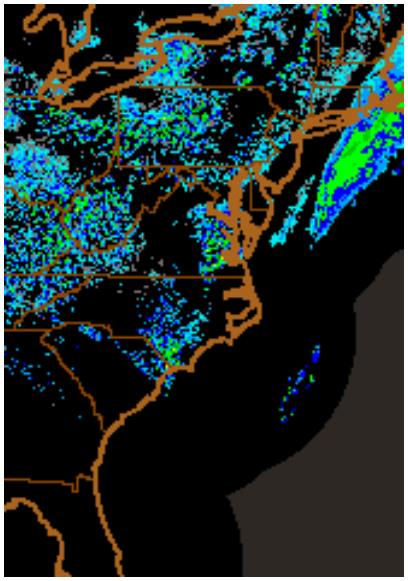
(1) Extended range lightning data (proxy for reflectivity)

(2) Wind energy (tower, nacelle, sodar) observations

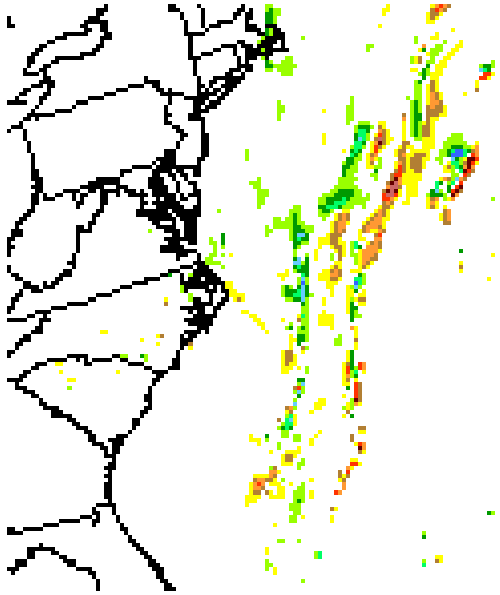
(3) Radar radial velocity



LTG flash density



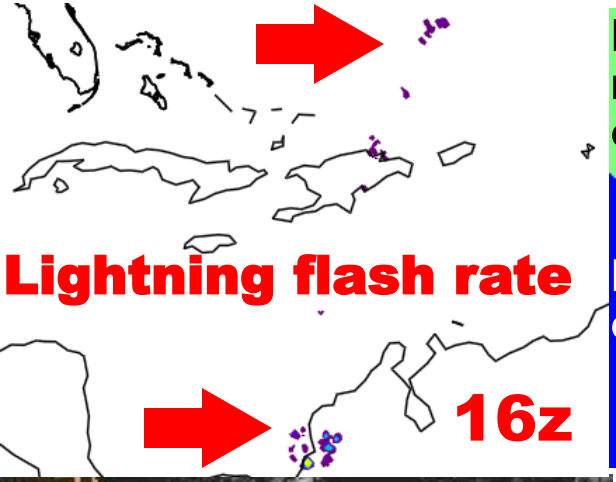
Obs reflectivity



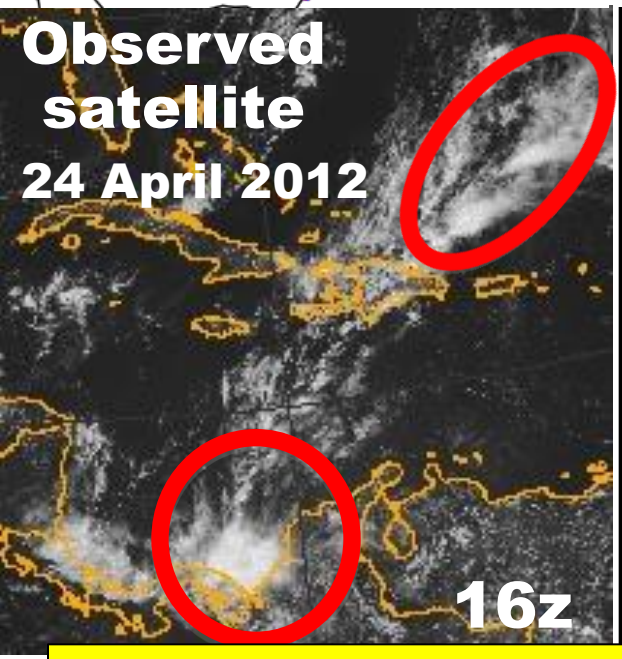
1h fcst refl. diff between RAP w/ and w/o lightning

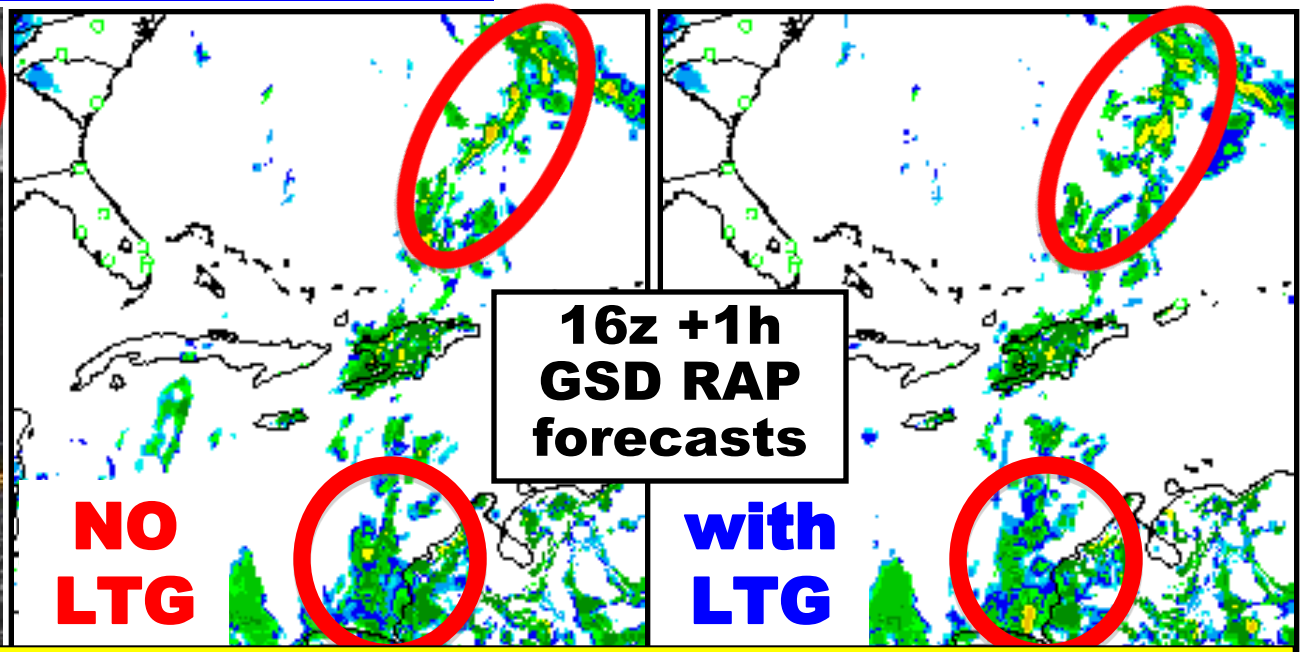
Merge RAP GSI code with GSI code from recent NCEP/community trunk versions

RAP Lightning Assimilation



Latent heating-based temper-ature tendency

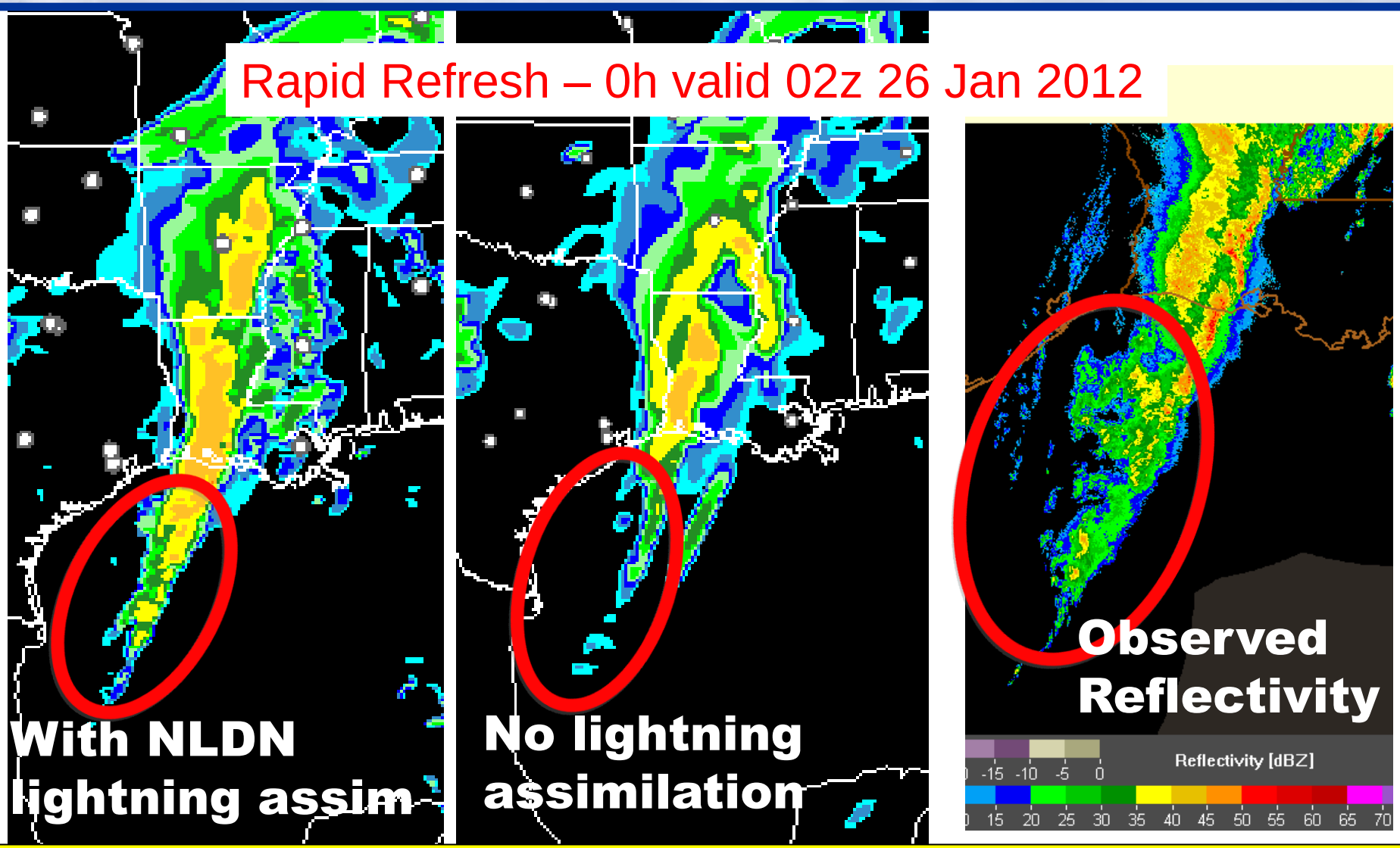




Improved storm / precipitation forecasts over oceanic / data sparse regions
from assimilation of extended range lightning data in Rapid Refresh model

RAP Lightning Assimilation

Rapid Refresh – 0h valid 02z 26 Jan 2012



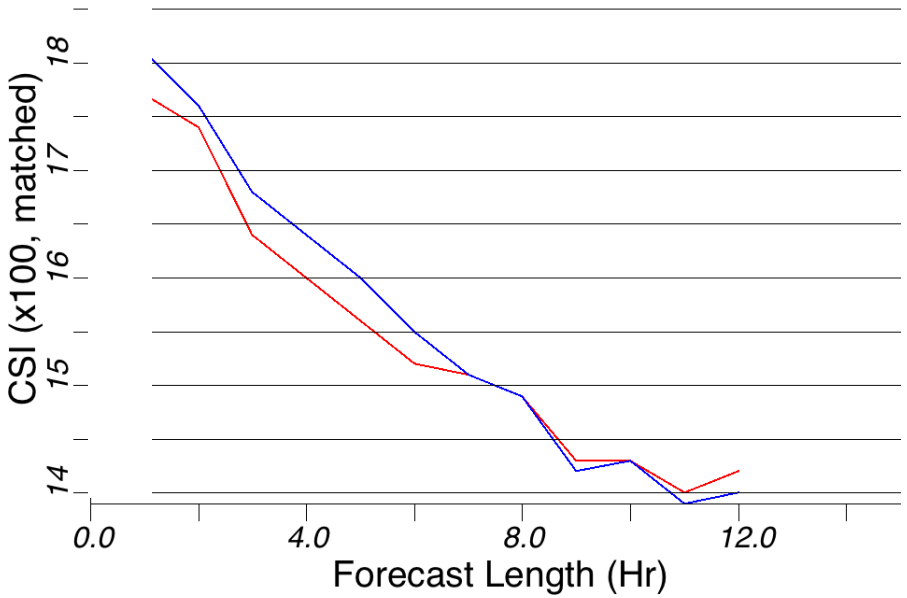
Improved convective coverage off the coast with lightning assimilation

RAP Lightning Verification

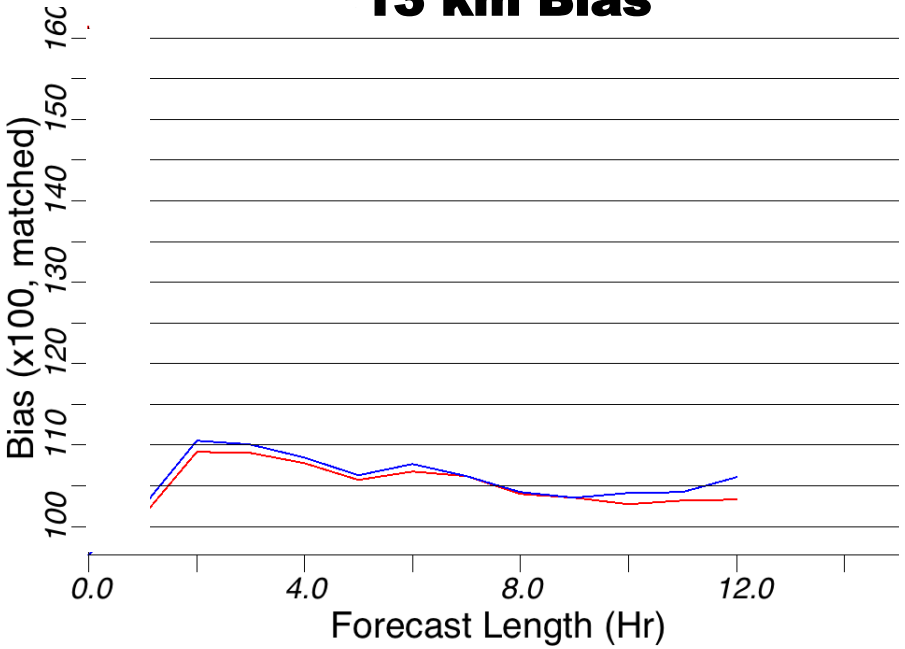
Reflectivity ≥ 20 dBZ
24 – 26 April 2012
CONUS

With LTG
No LTG

40 km CSI



13 km Bias

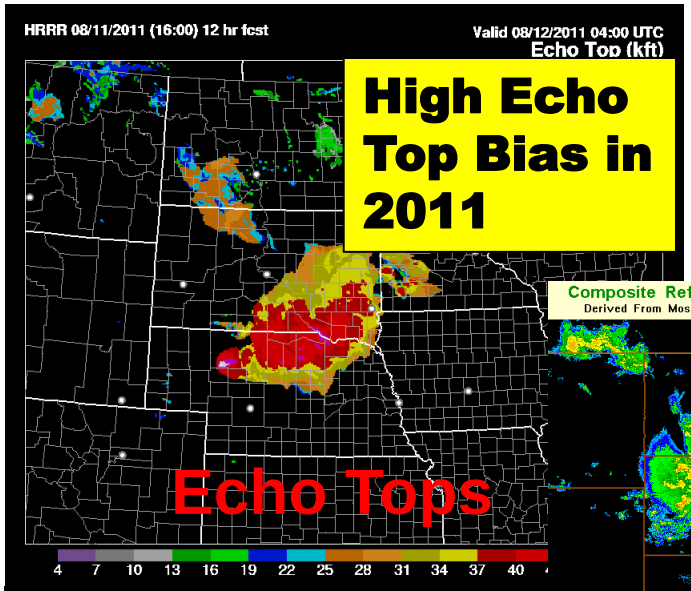


Slight improvement in RAP skill with lightning assimilation

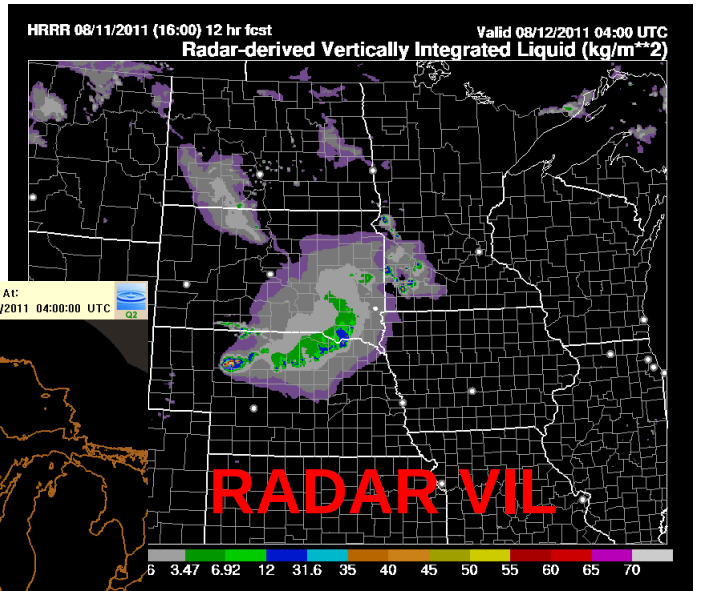
HRRR Echo Top Calibration

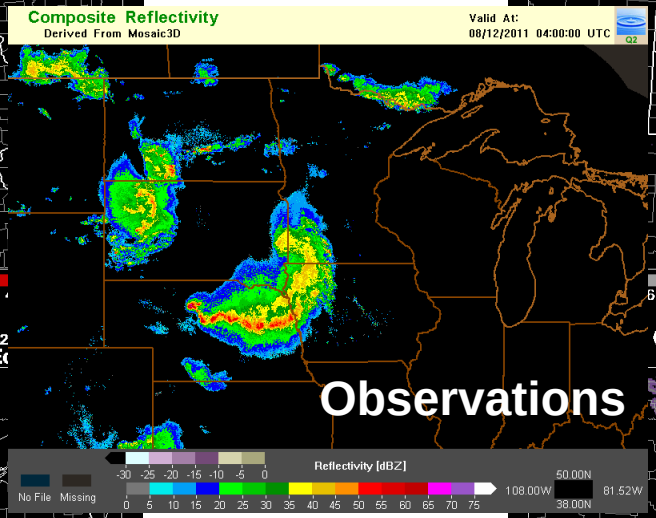
HRRR 2011

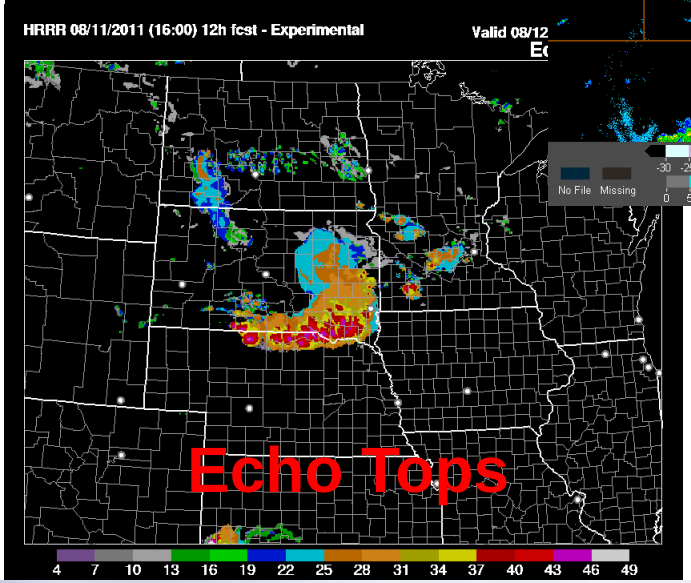
HRRR 2012

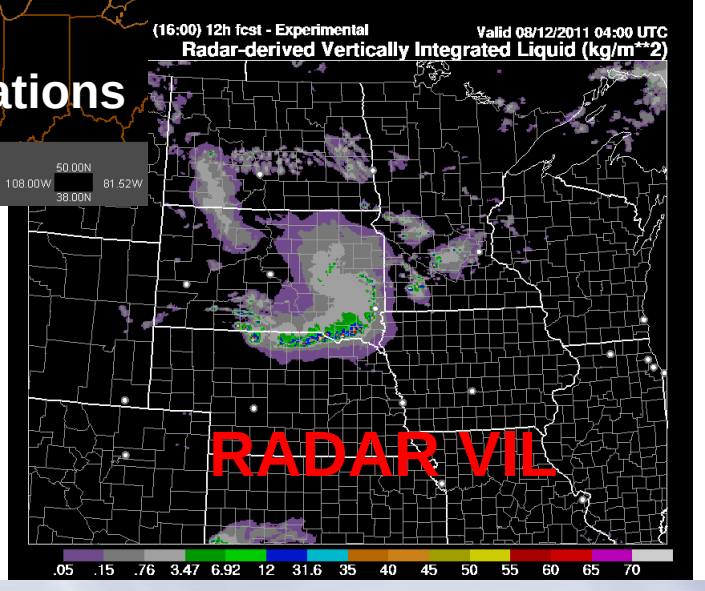


12 hr Fcst Valid 04 UTC 12 Aug 2011



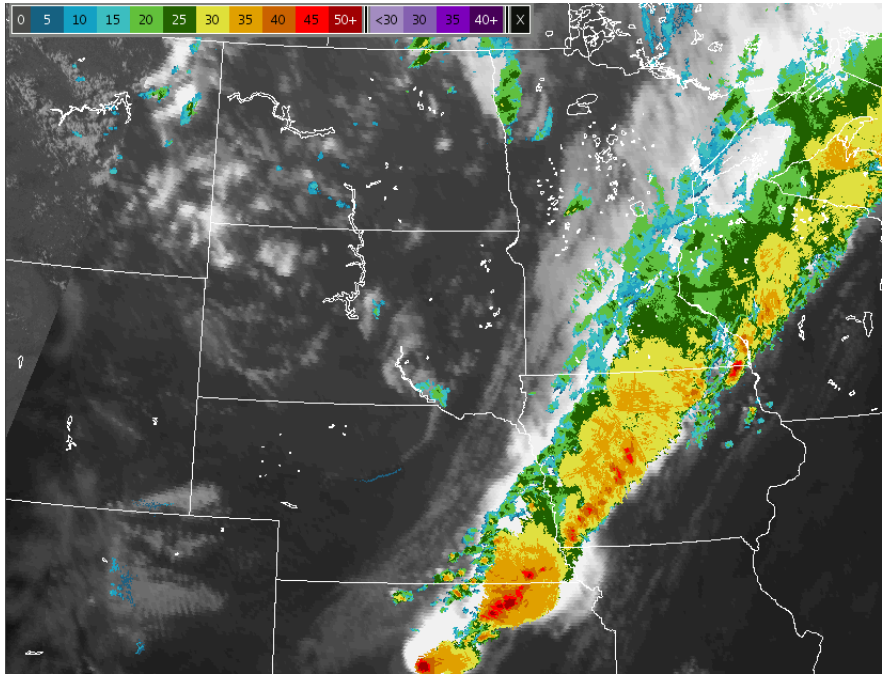






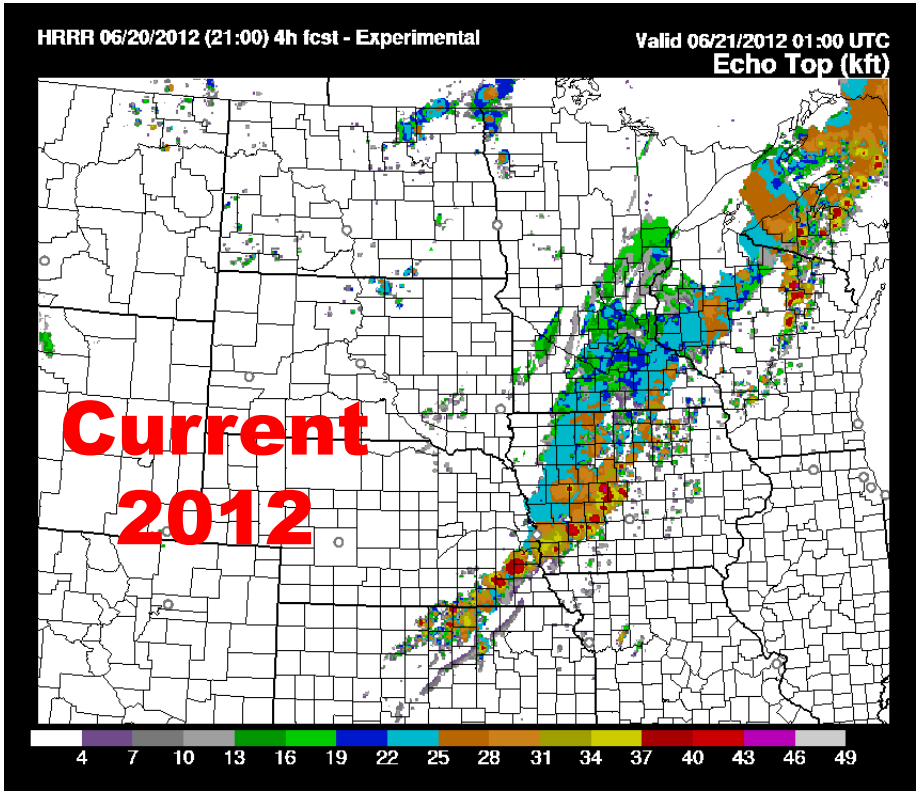
HRRR Echo Top Calibration

Observation
01z 21 June 2012



Echo Tops (kft)

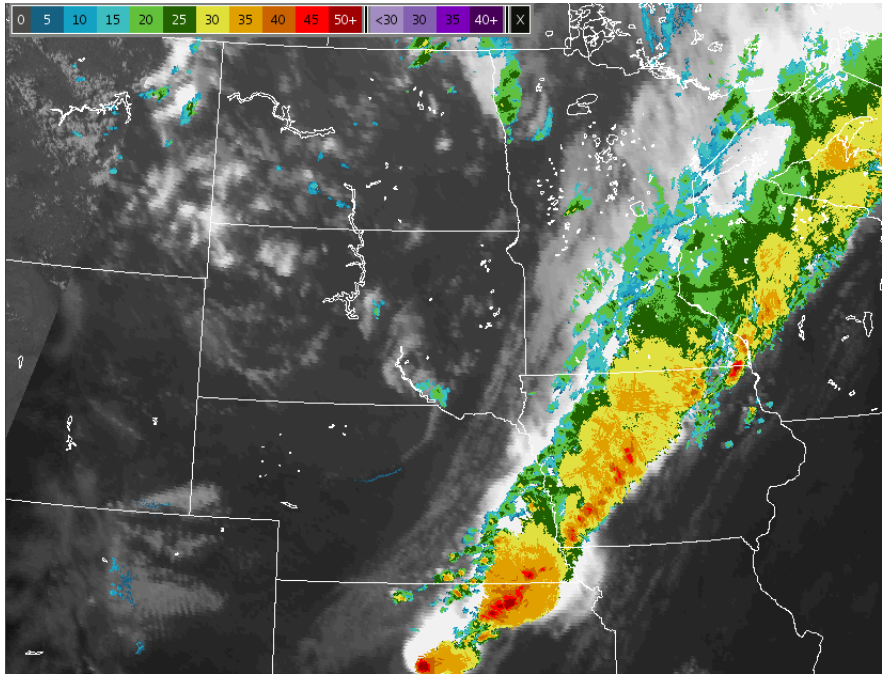
HRRR 4 hr forecast



Current 2012 low bias in echo tops

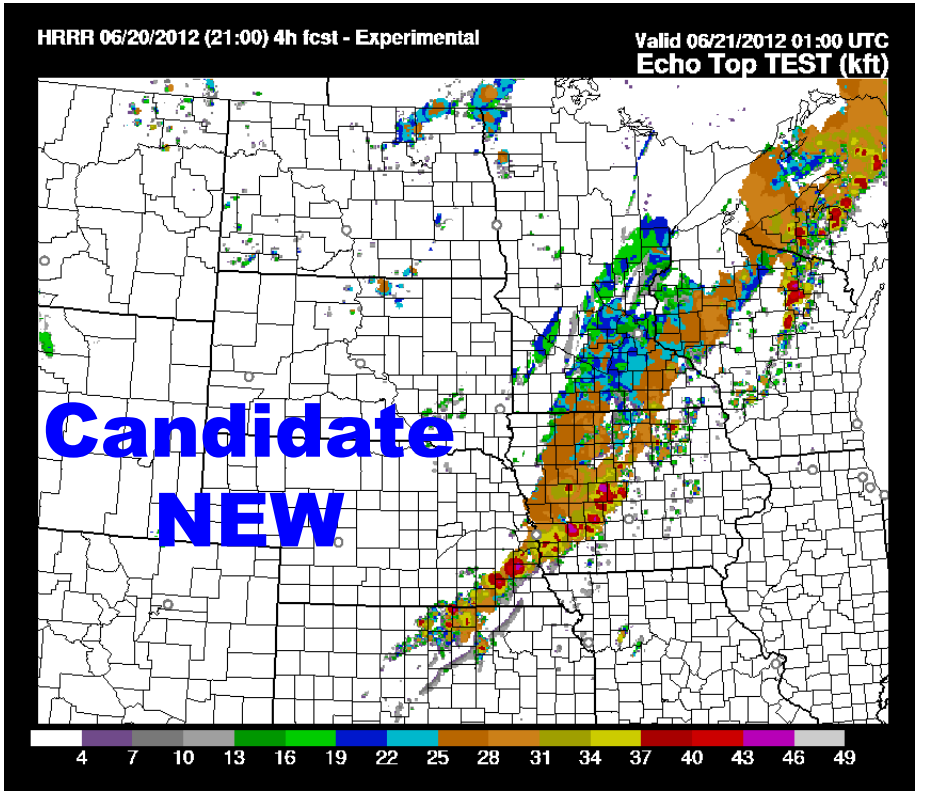
HRRR Echo Top Calibration

Observation
01z 21 June 2012



Echo Tops (kft)

HRRR 4 hr forecast



Calibration of echo tops to produce improved bias

Retro Assessment Summary

- **RAP/HRRR moist bias has been reduced in 2012**
  - Reduction in HRRR false alarm convection (including initiation)
  - Improvement in mesoscale convective system (MCS) maintenance
  - Improvement in skill of timing and structure of convective forecasts
  - More uniform HRRR reflectivity bias with lead time (first 6 hrs)

- **Slight positive impact from lightning assimilation**
  - Improvement in RAP convective forecasts over oceanic regions
  - Improvement in RAP forecasts in areas w/o radar coverage

- **HRRR Echo Top Calibration**
  - High bias in HRRR forecasted echo tops in 2011
  - HRRR reflectivity diagnostic consistent with microphysics in 2012
  - Low bias in HRRR forecasted echo tops in 2012
  - Ongoing effort to calibrate HRRR echo top diagnostic